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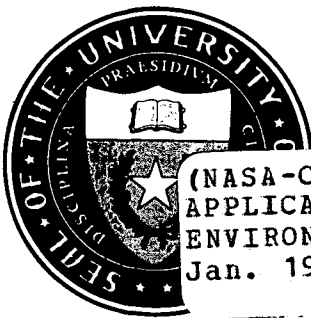
FINAL REPORT

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**PUBLIC HEALTH APPLICATIONS OF
REMOTE SENSING OF THE ENVIRONMENT
(An Evaluation)**

DRAFT

**CONTRACT NUMBER NAS-9-11522
MANNED SPACECRAFT CENTER
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION**



(NASA-CR-129822) PUBLIC HEALTH
APPLICATIONS OF REMOTE SENSING OF THE
ENVIRONMENT, AN EVALUATION (Texas Univ.)
Jan. 1972 158 p CSCL 06E

N73-14069

Unclas
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**THE UNIVERSITY OF TEXAS
SCHOOL OF PUBLIC HEALTH AT HOUSTON**

JANUARY 1972

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ABSTRACT

During the year in which this contract was in force a number of investigators on the faculty of The School of Public Health at Houston, The University of Texas, examined the available techniques in the field of remote sensing (including aerial photography, infrared detection, radar, etc.) and determined how these might be applied to a number of problems in the wide field of public health. The specific areas of public health examined included: air pollution, water pollution, communicable disease, and the combined problems of urban growth and the effect of disasters on human communities. The assessment of the possible applications of remote sensing to these problems was made primarily by examination of the available literature in each field, and by interviews with health authorities, physicists, biologists, and other interested workers.

Air pollution is a serious and growing problem, not only from the aesthetic viewpoint, but also as a very real health problem, particularly for older citizens, or those with some impairment of the respiratory system. Three types of programs employing remote sensors were outlined in the air pollution field: 1. proving ability of sensors to monitor pollutants at three levels of interest - point source, ambient levels in cities, and global patterns; 2. detection of effects of pollutants on the environment at local and global levels; 3. routine monitoring.

Three specific work programs were proposed, based on these general considerations. A survey of instrumentation available or under development for air pollution detection particularly for gaseous pollutants, indicates some promising leads, but little practical use as yet.

As with air pollution, the degradation of our fresh and salt water bodies has very direct health consequences, as well as the more obvious aesthetic consequences. During this study all of the major groups of effects one might wish to study in water (physical, chemical, botanical) were listed and the appropriate instrumentation for each discussed. Some use has already been made of remote sensing in detection of oil spills, and in the visualization of thermal pollution as an indication of possible industrial and municipal discharges into water bodies. While several present sensors show promise there is need to obtain more information on the depth penetration qualities and other instrument capabilities in a wide variety of aquatic situations. There is also a pressing need for more ground truth data, for instance in relating sensor-detectable environmental qualities to the presence of sewage pollution.

In assessing the role of remote sensing in the field of communicable disease the project personnel examined a list of the known human diseases of this type, and selected only those which showed varying degrees of promise for further examination in the context of remote sensing. Some of these either are very imperfectly known in their ecologies, or seem to offer relatively little in the remote sensing field - and these are listed in tables in the body of the report. In malaria, however, still the major disease problem in many parts of the world, remote sensing may assist in plotting the distribution of certain vector mosquitoes, and

in plotting the distribution of human population groups under difficult terrain features. Onchocerciasis is a highly terrain-oriented disease, transmitted by blackflies, which breed only in specialized streams. Plotting of these streams and subsequent control campaigns might be greatly accelerated by remote sensing. In Africa the distribution of this disease is changing rapidly as water is impounded - the same is true of schistosomiasis. The distribution of the snail hosts of that serious disease might be plotted by remote sensing techniques.

In the more arid portions of the world, including the southwestern United States flea-borne sylvatic plague and the dust-borne coccidiomycosis appear to have elements amenable to remote sensing. Anthrax, primarily a disease of livestock important to human nutrition, is under active study at present, to determine if soil and vegetational features indicate danger areas. Plotting of the distribution of fire ants in the southern United States appears to be an immediate practical use of remote sensing.

Determination of the extent of breeding by mosquitoes appears to be one of the most promising applications of remote sensing, but a very great deal of detailed ground truth data remains to be assembled for almost all important species. The same is true of the application to plotting the suitable pupal habitats for such diverse species as the screw worm fly in Mexico and Central America and the tsetse vectors of sleeping sickness in Africa.

The field of urban growth, its influence on human disease, and the allied question of the assessment of the results of natural disasters

appear to have considerable promise for application of remote sensing. Aerial photographic techniques have long been used in urban growth studies, and recently infrared and other sensors have also been applied. A list of urban studies with public health implications is provided in the report, with some specific suggestions for further work. One additional area was examined, although not included in the original statement of work - radiological monitoring, particularly in radiological emergencies.

Wherever possible, the report includes specific recommendations for further study, and specific budgets. In many cases the various agencies of the federal government are best qualified and equipped to undertake the ground truth studies. Despite all the very promising applications which are discussed in the report, almost nothing appeared in the literature during the year in which it was in preparation indicating that active programs in the public health field were being pursued. In general, this appears to be due to the relative newness of the remote sensing field, and the need for far more detailed ecological data than has been available heretofore in almost every situation. It is strongly recommended that steps be taken to obtain such data as rapidly as possible for the most promising applications listed in the report.

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Note: This final report summarizes a number of topics discussed in the interim quarterly reports, and makes a number of proposals for additional work on promising leads. A limited number of copies of the quarterly progress reports, including the bibliographies are available on request to the contractor.

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1. INTRODUCTION

Remote sensing, in the meaning employed in this report, and in the literature in the field, refers to the application of optical and electronic technology to the detection and evaluation of environmental features. The platforms from which the various instruments operate may be either aircraft operating at various altitudes in the atmosphere, or satellites or spacecraft in moving or synchronous orbits above the atmosphere. The field of remote sensing as so defined now has a fairly long history, and one which has made noteable contributions to human progress.

In the consideration of the extension of the reach of human senses it might be well to point out that of the five recognized physical senses only two (touch and taste) require direct contact with the object being detected or analyzed, while the other senses (sight, hearing, smell by their nature may operate over some distance). The field of remote sensing as we understand it here, however, is characterized by the extension of the human senses (particularly sight) over extreme distances; and, in the case of sight, into portions of the electromagnetic spectrum not discernible by the unaided eye. Further, data may be gathered in such a manner as to permit storage and analysis by computers. Some of the techniques employed will be described below and

are presented in much more detailed form in the National Aeronautics and Space Administration (NASA) publication "Earth Resources Program Synopsis of Activity", March, 1970 (1), and a number of texts (2, 3).

As noted above, the use of elevated platforms for extension of human observation has some modest amount of history. The earliest examples are from military history, as is true of so many of our technological advances. During the U.S. Civil War a corps of balloonists was employed by Union Forces to observe troop movements, a concept which was continued through World War I. The first aerial photographs were made from balloons in 1858, and by the end of World War I thousands of aerial photographs were being taken daily from aircraft. In addition to military applications aerial photographs were used for mapping, geology, oil surveying, forestry and crop surveying, and many other civilian purposes. During and after World War II color and infrared photography greatly expanded the capabilities of aerial photography in detecting subtle differences in terrain features, vegetation, etc.

The development of space vehicles carried aerial photography not only to higher altitudes, but led to the development of improved photographic techniques. Perhaps of even greater importance has been the development of other sensing devices in addition to photographic methods. These include: infrared scanners, side-looking imaging radar, microwave radiometers and laser devices. As in other fields of science, the results of space research and technological development have increased at a tremendous rate in the last two to three decades, and many of the devices developed for sensing of atmospheres, surface features and other

elements on astronomical bodies other than earth have been found to have immediate application to problems in the human environment on earth. These were first applied on a large scale in the fields of forestry (for detection of diseases and insect damage), agriculture (for the same purposes, and for crop inventory), and the various marine biological and physical sciences. Many such applications are described in detail in the texts listed in the bibliography (2, 3). Some applications, including the great advances in meteorology represented by systems such as the Nimbus series of satellites, have become familiar to the general public - others are just reaching the level of public consciousness, such as the recent application of remote sensing to detect the advance of corn blight.

Despite the ten to fifteen years of experience with various earth observations applications of remote sensing on the part of NASA, many of its contractors, universities and various branches of government, almost nothing was done of direct interest to public health, at least in the narrow sense in which this term is usually understood. Advances were made in air and water pollution detection, oil spills, urban growth patterns and the classification of neighboring quality. All of these elements are decidedly part of the inclusive view of public health which has been coming to the fore in recent years.

In view of the facts summarized above, the Public Health Ecology Section of the Manned Spacecraft Center, NASA submitted a request for a proposal to the School of Public Health at Houston to examine a wide range of problems in the public health area and determine which of them

might be amenable to application of remote sensing in their definition and solution.

Five major areas have been examined: air pollution, water pollution, communicable diseases, urban development and disaster survey, and radiological monitoring. The latter section was added in the final report as a preliminary suggestion and did not appear in the quarterly reports. Each of these topics is discussed below.

In conducting this study, and in accordance with the original statement of work furnished by NASA the project staff has examined as many of the current concepts in the broad field of public health as possible, has attempted to determine which of these problems has a significant component of environmental factors which might be amenable to remote sensing, has examined the techniques available (including only those discussed in the open literature and not considering any classified projects or techniques), and assessed the possibilities inherent in the techniques. It should be emphasized that this contract has not included any experimentation with the techniques of remote sensing, nor the actual coupling of ground truth acquisition with remote sensing flights. Some activities of this sort were conducted by SPH personnel in cooperation with the Public Health Ecology Section-MS, but these were outside the scope of the present contract and are covered in other documents.

Wherever possible the sections of the report which follow contain specific suggestions for further work, as outlined in the original statement of work. In some cases it has been impossible to arrive at

estimates for cost of such suggested projects, since they are in such early formative stages.

A short introductory section on remote sensing techniques is included for readers of this report who may be unfamiliar with the general field of remote sensing.

One further introductory note should be made. No attempt has been made to assess the operational cost of the various applications suggested. Estimates for programs listed are only for ground truth accumulation or for further preliminary investigation. In general, the personnel who prepared this report are not familiar with the actual costs of remote sensing operations, from aircraft or spacecraft. Furthermore, the field is in such a rapid state of development that any assessment of cost based on present equipment would probably become obsolete rather rapidly. It seems obvious to us, however, that the operations are so expensive that continued development must depend primarily on interested national governmental agencies. Furthermore, except in the most highly developed countries it is unlikely that public health agencies will be able to obtain or operate the necessary equipment, with the exception of relatively unsophisticated aerial photographic techniques. At a recent series of technical discussions on recrudescences of arthropod-borne diseases sponsored by the Pan American Health Organization in Washington it was estimated that many developing nations had as little as five United States dollars per capita per year to spend on national health programs.

It is therefore anticipated that the continued development, as well as public health applications, of remote sensing techniques will largely have to be provided for health agencies as a service by NASA or other appropriate agencies. It is particularly important that as many simultaneous needs as possible (geology, mapping, agriculture, forestry, public health, etc.) be served by single remote sensing missions - requiring the utmost in cooperation among the governmental and private agencies involved.

During the year in which this project was undertaken, and in which the three quarterly reports and this final report were prepared, over three hundred separate publications, reprints, texts technical reports and reprints from journals were examined. By the closing date of the final report there was still only one scientific paper in the literature which dealt specifically with the application of remote sensing to the broad field of public health. This was the paper by Dr. Cline entitled "New Eyes for Epidemiologists: Aerial Photography and Other Remote Sensing Techniques" which appeared in 1970 (American Journal of Epidemiology, Vol. 92: 85-89). Dr. Cline participated as a consultant in the preparation of the present report and indicates that while he has had a number of inquiries from interested workers as a result of the article, no similar paper has appeared reporting new work. It appears that the Public Health Ecology Section, MSC is the only agency devoting its energies to this field.

2. REMOTE SENSING TECHNOLOGY

The Electromagnetic Spectrum - Remote sensing is a term applied to the gathering of information from a more or less distant vantage point. The carrier of the information is usually electromagnetic radiation, but static fields have been employed.

Remote sensing devices are divided into two classes, active and passive. Passive sensors rely on natural sources of electromagnetic energy while active sensors are employed with artificial sources.

Electromagnetic radiation consists of sinusoidally varying electric and magnetic fields propagating with a velocity c . The electric and magnetic fields are at right angles to each other. The radiation is further characterized by a wavelength, λ and a frequency, f which are related to the velocity by the equation

$$\lambda f = c$$

Although wavelengths of electromagnetic radiation range from thousands of meters to less than 10^{-13} meter, only certain portions, or bands of radiation are useful for remote sensing. For earth applications, reasonable transmission through the atmosphere is a minimum requirement. Extremely long wavelengths are impractical because the maximum resolving ability (spatial) of diffraction limited imaging system is on the order of the wavelength of the radiation employed. Extremely short wavelength radiation is of limited usefulness because it cannot be imaged.

When electromagnetic radiation encounters matter, fractions of the initial intensity may be scattered, reflected or absorbed. Objects illuminated with electromagnetic radiation will return a signal which is dependent upon the physical configuration and composition of the illuminated object and the wavelength of the radiation. In addition, any object whose temperature is above absolute zero will radiate electromagnetic energy whose spectral characteristics and intensity will be functions of the temperature and emissivity of the object. Remote sensing seeks to identify certain objects or conditions or classes of objects or conditions by their morphology and the ways in which they differentially scatter, absorb, reflect and/or emit various wavelengths of radiation.

The maximum information concerning an area under investigation would consist of a large number maximum resolution (spatial) images of the area. Each image would be formed with a different wavelength radiation. Both active and passive sensors could be employed. The number of images would be governed by the spectral resolution of equipment. In practice, it would be difficult to interpret it. Furthermore, there would be more information than would be required to perform the task under consideration. Thus, in practice, a signature is developed for the identification of certain objects or conditions. A signature is most easily explained by example. One of the early uses of remote sensing was the detection of camouflage. While green leaves and green camouflage may appear identical in color to the eye, the reflectivity

of camouflage materials in the near infra-red is considerably less than that of green leaves. Thus, the spectral signature of camouflage materials (relative to green leaves) is low reflectivity in the infra-red. Thus, a portion of the work in remote sensing consists of identifying spectral or spatial signatures for objects or conditions that are to be identified or differentiated.

Description of equipment - available or under development - The available sensors for remote sensing of ground based data utilizing NASA-MSC spacecraft have been fully documented elsewhere (4). However, the following brief description of remote sensing systems is included for ready reference to the following sections of the report.

Table 1. Sensor Systems

1. Camera Systems

a) Wild Heerbrugg RC8 Camera

Features: 9 by 9 in. Format

6-in. Focal length lens

F/5.6 Avigon lens

Rotary shutter

Shutter speed: 1/100 to 1/700 sec.

Cycle rate: 1 cycle/2 sec. max.

Field of vision (FOV): 91° Diag.

f-stops: 5.6 to 22

Spectral Range 0.4 to 0.92 μ m

b) Zeiss RMK 30/23 and 15/23 Camera

Features: 9 by 9 in. Format

12 or 6 in. Focal length camera lens

F/5.6 Topar lens

Reseau Grid

Rotary Shutter

Shutter speeds of 1/100 to 1/1000 sec.

Spectral range of 0.4 to 0.92 μm

Cycle rate: 1 cycle/sec. max.

f-stops: 5.6; 8; 11

FOV - 30/23 camera, 47°; 15/23 camera, 93°

c) Chicago-Aerial KA62 Camera

(Four-camera Multiband System on NP3A aircraft)

Features: 5 - by 5 in. Format

3-in. Focal length lens

F/4.5 PAXAR lens

intralens shutter

Shutter speeds: 1/160, 1/90, 1/125, 1/175,
1/390, 1/500 secs.

Cycle rate: 1 cycle/sec. max.

FOV: 92° diagonal

Spectral Range of 0.4 to 0.92 μm

d) Hasselblad EL 500 Camera

(Four - or six camera Multiband System)

Features: 70 mm Format

Lenses: 40mm, f/4 to 32^{var.}, FOV: 88° diag.

50mm, f/4 to 22 75° diag.

80mm, f/2.8 to 22^{var.} 52° diag.

120mm, f/5.6 to 45 36° diag.

150mm, f/4 to 32 29° diag.

250mm, f/5.6 to 45 18° diag.

500mm, f/8 to 64 9° diag.

Intralens shutter

Shutter speeds: 1/30, 1/60, 1/125, 1/250, 1/500

Cycle rate of 1 cycle/sec. max.

Spectral range of 0.4 to 0.92 μm

e) Chicago Aerial KA50A Camera

(High-acuity aerial-reconnaissance camera)

Features: 5 by 5-in. Format

1.75 in. focal length lens

F/5.6 Super AVIGON Lens

Focal-Plane Shutter

Shutter speeds 1/25 to 1/400 sec. variable

Cycle rate: 1 Cycle/sec. max.

FOV: 120°

f-stop: 5.6

Spectral range of 0.4 to 0.92 μm

f) Flight research model 207 Camera (Boresight)

(Provides boresight reference for primary sensors)

Features: 35mm format

Focal length lenses 25, 75, 120, 200mm

Variable shutter aperture: 6 to 120°

Shutter speeds: variable to 1/1200 sec.

Cycle rate: 2 frames/sec. max.

PIN Registration

Lenses: 25mm, FOV 53°

75mm, FOV 19°

120mm, FOV 9.5°

200mm, FOV 7°

Spectral range: 0.4 to 0.7 μ m

2. Laser Systems

a) Laser Profiler

Description: Absolute-altitude measuring device. Transmits monochromatic laser beam, detects beam reflectance, and measures phase delay.

Features: Continuous wave, helium-neon laser

6328A wavelength

40mW output

Range steps: 10, 20, 40, 100, 1000, 10,000,
100,000 ft.

Resolution: 0.003 ft. at 49.16471 M Hz

Range: 3000 ft. max. in full sunlight

Modulation frequencies: 49.16471 M hz to

4.91647 lc hz in multi-

ples of 10

Readout: Reflectometer output

3. Infrared Systems

a) Filterwheel spectrometer

Description: Utilized circularly variable interference filter as a spectral dispersing element.

Records Infrared radiation.

Features: System is boresighted with the infrared radio-meter and boresight camera.

Circularly variable filter

All reflective system

Heated internal reference source

No inflight calibration

Spectral range: 6.7 to 13.2 μ m

6.5 scans/sec.

Resolution: 1.5% of wavelength

Spatial Characteristics: 7mRAD FOV

e.g. 7 ft. at 1000 ft.

altitude

Readout: Magnetic Tape

b) Infrared Radiometer

Description: Single-channel infrared radiometer

Features: Boresighted with filter wheel spectrometer

Radiance from ground chopped against adjustable internal reference source

Spectral range: 10.375 to 12.1 μm

Spatial Characteristics: 7mRAD FOV

Readout: Analogue on strip charts

c) Precision Radiation Thermometer (PRT-5)

Description: Thermal Infrared Radiometer

Features: Spectral Range: 8 to 14 μm

Single bandpass filter

2° FOV, e.g. 35 ft. at 1000 ft. altitude

350 ft. at 10,000 ft. altitude

Measures: -20 to +15°C, +10 to +45°C

+40 to +75°C

Readout: Analogue on magnetic tape

Display of equivalent blackbody temperature on instrument dial

4. Imaging Line Scanners

a) 24-Channel Multispectral Scanner

Description: Scans successive continuous lines across flight path and records simultaneously in 24 discrete spectral intervals.

Features: Calibration sources

Spectral characteristics:

Range: 0.34 to 13 μm

Intervals from 0.4 to 1.0 μm bandwidth

Resolution: 2mRAD, e.g., 2 ft. at 1680 swath ft.
and 1000 ft. altitude, 80° FOV $\pm 40^\circ$
from NADIR

Readout: Analogue multiplexed on 12 tracks of
magnetic tape

b) RS-14 Dual Channel Scanner

Description: Radiometer that scans successive contiguous
lines across the flight path and records 2
or 5 discrete spectral intervals

Features: Internal calibration

Spectral characteristics:

Choice of ranges on 2 channels

Channel 1: 0.3 to 5.5 μm ,

Channel 2 only 8 to 14 μm

Resolution: 3m RAD at 1680 ft. swath and 1000 ft.
altitude, e.g. one foot
 80° Scan ($\pm 40^\circ$ from NADIR)

Readout: Magnetic Tape

c) RS-7 Infrared Scanner

Description: Single channel radiometer that scans contiguous lines across the flight path and records infrared energy.

Features: Spectral Characteristics

100° scan (± 50° from NADIR)

Spectral Range: 8 to 14 μ m or 10 to 12 μ m

Resolution: 1m RAD FOV

e.g. 1 ft. with 2400 ft. swath

from 1000 ft. altitude

Image recorded on 70mm film

No calibration

d) RECONOFAX IV Infrared Scanner

Description: Single channel radiometer that scans contiguous lines across flight path and records infrared energy.

Features: Inflight calibration

Spectral Characteristics

Range: 8 to 14 μ m or 8 to 10.5 μ m

60° scan (± 30° from NADIR)

3m RAD FOV (Instantaneous)

e.g., 3 ft. with 1150 ft. swath

from 1000 ft.

Readout: Image recorded on 70mm film

5. Passive Microwave Systems

a) Multifrequency Microwave Radiometer (MFMR)

Description: 4 Channel Microwave radiometer which records thermal energy.

Features: May be stationary or scanning

Records: 1/420 G hz on one channel-L

10.625 G hz - Channel X

22.235 G hz - Channel K

31.4 G hz - Channel K_a

Spatial characteristics:

16°±0.5° 3dB beam width, Channel L

5°±0.2° 3dB beam width, Channels X, K, K_a

560 ft. resolution at 2000 ft. altitude for
Channel L

175 ft. resolution at 2000 ft. altitude for
other channels

Analogue output recorded on tape and displayed
on strip chart

b) Passive Microwave Imaging System (PMIS)

Description: Passive dual-polarized constant angle of
incident microwave images which record micro-
wave energy.

Features: Spectral characteristics

1 Channel - 35dB sidelobe Taylor distribution

10.69 Ghz and 200 Mhz bandwidth

70° Scan ± 35° from NADIR

Resolution: 60 ft. with 1000 ft. swath from

14,000 ft. altitude

Readout: Recorded on magnetic tape

6. Active Microwave Systems (RADAR)

a) 16.5 Ghz Side Looking Radar (SLAR)

Description: Radar mapping device which produces photograph-like images from transmitted pulses of horizontal and vertical polarization

Features: Spectral Region: 16.5 Ghz \pm 5M hz

Resolution: 45 to 87 ft.

Readout: Film

b) 400 MHz Scatterometer

Description: Records Radar radiation - back scatter cross section per unit surface area versus incident angle after transmission of vertical and horizontal polarized radiation.

Features: 9 Channels (1 calibration, 8 data)

400 Mhz transmission

60° FOV, 7.5° crosstrack (\pm 3.75° NADIR)

Resolution: 174 ft. swath width from 2000 ft.
altitude

Readout: Multiplex data to analogue channel for
spectrum analyzer display

c) 13.3 Ghz Scatterometer

Description: Records Radar radiation backscatter cross section per unit surface area versus incidence angle.

Features: Internal calibration

One channel 13.3 Ghz

Spatial characteristics

120° by 3.0° beam width

Resolution 150 ft. along flight path at 2000 ft. altitude

Readout: Recorded on Magnetic Tape, displayed on CRT.

7. Environmental Sensors

a) Liquid Water Content Indicator

Description: Measures and records liquid water content of environment outside craft.

Features: 2 scales; 1.0 to 2.0, 2.0 to 6.0 g/m³

Response: 2g/m³/sec/200 KNTS

Recorded on tape, dial display, and/or strip chart recorder

b) Total Air Temperature (TAT) Indicator

Description: Thermistor senses total air temperature

Features: Sensitivity of 0.01°C

Accuracy of 1.0°C

Range: 200° to 600° Rankine

40°R/sec response time

Readout: Meter, Strip Chart, or Dial

c) Dewpoint Hygrometer

Description: Records Dewpoint and Frostpoint of air outside craft.

Features: Measures dewpoint & freeze point from -50° to +50°C. 3°C/sec response time

Readout: Meter, strip chart, or dial

8. S190 Multispectral Photographic Facility

Description: 6-Channel Camera System which measures visible and infrared energy.

Features: Spectral characteristics

6 filtered Bandwidths, 0.4 to 0.9 μ m

Controlled shutter speeds and intervals between exposures.

Shutter speeds of 2.5, 5 and 10

F/2.8 matched lenses

6 in. focal length

70mm film 2.25 by 2.25 in format

Resolution: 100 ft. from 235 NMi

1 ft. from 10,000 ft.

9. S191 Infrared Spectrometer

Description: Filter wheel spectrometer utilizing circularly variable interference filters. Possible quantitative evaluation of energy measured in ranges of 0.4 to 2.4 μm and 6.2 to 15.5 μm region.

Features: Internal wavelength and calibration

Spectral characteristics: 0.4 to 2.4 μm

6.2 to 15.5 μm

1 scan per second

1m RAD instantaneous FOV

10 in. Cassegrain collecting telescope

Readout: Tape decommutated and reformatted on ground

10. S192 Multispectral Scanner

Description: Radiometer that scans successive contiguous lines across the flight path and records visible and infra-red energy simultaneously in 10 discrete spectral intervals.

Features: Sensitivity of 0.4°K

Line-scan imagery

Each channel calibrated 100 times/sec.

Spectral separation by dispersion

10 spectral bandwidths from 0.4 to 12.5 μm with

bandwidths from 0.1 to 2.3 μm

10° scan 40-IN Mi Swath width with 4 Bands of 0.91 m

RAD IFOV (instantaneous field of view) and 6

Bands of 0.182 m RAD IFOV

Resolution: 4 Bands - 130 ft.

6 Bands - 260 ft.

Readout: 22 data channels recorded

11. S193 - Microwave System

Description: Combination Active and Passive Microwave System

which compares surface brightness temperature measurements at two microwave frequencies by simultaneous measurement of radar scattering cross section and microwave emissivity and signal-correlation properties. Receives dual-polarized radiation.

Features: Select scan mode; contiguous, non-contiguous, cross-track, along track.

Select instrument combination: radiometer, altimeter, scatterometer, radiometer.

Transmits and receives from 13.8 to 14.0 GHz

At 230 NMi, illuminates 6-NMi cone at NADIR

Readout: 10 Kilobit PCM multiplexed on one tape recorder track.

Note: All S numbered instruments were designed for use with SKYLAB -A.

Several instruments now under development may be utilized in future programs dependent on remotely sensed data. Several of these new systems are described in the following table (Table 2):

Table 2. Sensor Systems Under Development

1. The Bendix Modular Multiband Scanner (M²S)

Description: A passive spectrometer which scans wide areas for radiance information in the UV, visible and solar IR spectral regions. It may be used as a single channel fixed instrument or with added modules a multiband scanner.

a) Single-band Instrument

Features: Thermal scanner, 2.5m RAD resolution.

V/h capability of from 0.05 to 0.25

Single-band scanning through UV-visible-IR.

4 position filter with sensitivities related to selected detector and the selected band filter.

Broad-band thermal (8 to 12 μ) with a Hg: Cd: Te detector is better than 0.05°C sensitivity.

Automatic recording of black body reference temperatures

Recording capability for other operating parameters

Record video scan data on film or broad-band FM tape recorders

b) Multiband Instrument

Features: Beam splitter

UV to 1.1μ region detected by Spectrometer

$>1.1 \mu$ energy detected by the thermal detector

Scanning rate: 20 to 100 rps, analogue var.

Shutter Operation: Manual

Filter Assembly: Manual

Detector Preamplifier Module

Photomultipliers, Silicon, In:Sb, Hg: Cd: Te

11 bands: 10 bands in distinct spectral regions

of <4.1 to 1.0μ and 1 band centered at

10.0μ .

2. Long-Path Spectrophotometric Instrument

Description: A passive, variable wavelength (7 to $14 \mu\text{m}$), spectrophotometer for quantitative measurement of ozone and other infrared absorbing gases in unconfined ambient air. It can be used in an active mode utilizing a transmitting source.

Features: Active Mode: Silicon carbide and alumina source

Range: 400 to 1600 meter distance

Passive Mode: radiometer

$7\text{-}14 \mu\text{m}$ variable wavelength selection

utilizes chopped incoming radiant energy.

Receiver optics include Dall-Kirkhan optical system.

f/1.5

continuous spectral scan

computer interfaced for data analysis,

0 to 64 channels

For 64 channels, 10 pollutants can be
detected

3. AIR POLLUTION

One of the major problem areas in public health is that of air pollution. The consequences of long term exposure to low levels of gaseous, liquid, and solid air pollutants are just beginning to be investigated. The consequences of exposure of the young and aged susceptible citizenry to acute air pollution episodes are tragic and well documented.

The concern for air pollution most often is manifested by urban residents concerned both for the aesthetic and health effects. Yet, the global consequences of man's intervention into the natural cycles of the biosphere may prove to be the ultimate catastrophe for mankind. Thus, there are two areas where concern for the presence of air pollutants is manifest: 1) the large metropolitan areas; 2) the world biosphere. A successful approach to either problem requires the ability to measure and monitor air pollutant concentrations on a regular basis.

Programs in the public health aspects of air pollution divide logically into several areas:

1. To prove the feasibility of utilizing remote sensors to monitor air pollutant concentrations at three levels of interest: single point sources, ambient air in metropolitan regions, global levels.

2. Utilization of remotely sensed data to identify the effects of air pollutants at the local and global levels.

3. Monitoring air pollution on a routine basis.

Many long-path, horizontal pollutant monitors are being developed based on principles of spectral energy absorption. Any one of these could be adapted as a device to measure the average vertical concentration of a specific pollutant. However, as of this date none have been developed beyond the stage of proto-type instruments.

The burgeoning world population and the increasing demand for a higher standard of living make it all but certain that industrial processes will expand for the foreseeable future. The logical method to solve this problem is to develop industrial and other processes which control air pollution at the source, and to make sure that adequate provision is made for this in the newly industrialized states. It appears, however, that there will be a need for the foreseeable future for methods for rapid detection of potentially harmful ambient air conditions, and for the detection of pollution sources, in which remote sensing may be expected to play a part.

Some of the phenomena of public health interest which may be expected to be detectable by remote sensing are outlined in Table 3.

Among the most interesting of the new generation of detection techniques is the remote heterodyne type, which can detect emitted radiation

by the use of Lasers as tunable local oscillators in the infrared part of the spectrum. The emission/absorption lines of many major atmospheric pollutant molecules overlap the operating frequency bands of CO₂ laser and CO laser heterodyne receivers. Ramon scattering has been utilized effectively for the sensing of pollutants, in particular SO₂, NO and other gases. However, its most useful application seems to be that of measuring atmospheric humidity.

The Fourier interference spectrometer developed at the Jet Propulsion Laboratory in Pasadena, California was designed for remote sensing of the environmental pollutants from space platforms. The signal to noise ratio has been improved and the system is now capable of measuring CO and CO₂ as a result of solar spectrum analysis. It is of interest that, on the average, pollutants seem evenly mixed from the ground up to the inversion layer, at least in the Los Angeles atmosphere.

Optical measurements of the mass of particles and the particle size diameter of those aerosols found in the atmosphere have become much better understood in the last year. In particular, nephelometers have been used to relate the visibility to the mass concentration of suspended particulates. Scattering measurements at several wave lengths have been correlated with the particle size distribution, and the variations of scattering with humidity have also been determined. It is possible that aircraft could be used to map distributions of particulate matter.

TABLE 3.

AIR POLLUTION APPLICATIONS OF REMOTE SENSING

Application	Phenomenon	Characteristic	Detector	Resolution Meters	Spectrum	Resolution
Gaseous Products of Combustion	Carbon Monoxide	Air Pollution from incomplete combustion				
	Carbon Dioxide	A natural com- ponent of air resulting from complete oxi- dation of carbon compounds				
	Oxides of Nitro- gen NO	Air Pollution from incomplete combustion	UV-Visible spectroradio- meter	4300 to 4500 Å		
	NO ₂	(Internal com- bustion)		1ppb/1000 meters		1ppm/1 meters
Particulates	Sulfur Oxides SO ₂	Air pollution from air oxi- dation of sul- fur compounds in fuels.	UV-Visible spectroradio- meter	1ppb/1000 meters	3025- 3275Å	1ppm/6 meters
	Inhalable particles	By-products of combustion and industrial pro- cesses	Infrared, color, photographs multichannel spectrophoto- meter	0.3		Indicative of scatter in several bands for mass mea- surement
	Cadmium - Toxic	Air pollution metal industries processes	None Develop- ed			
	Other Metallic Substances	Air Pollution from metal in- dustries pro- cesses	None Develop- ed			
Chlorinated Hydro- carbons Organic Phosphates						

Photochemical Phenomena	Complex Organic Compounds	Intermediates & other processes of photochemical reactions	M ² S	NASA Report N69-31961
Ozone Layer	Changes in Ozone Concentration	Product of Photochemical reactions spectrophotometer	Multi-band (M ² S)	0.1-1ppm/ 1000 meters Absorbs from 3200A ^o 2.8-4.3μm
Hydrocarbons			M ² S	3390A ^o 25-15.0 cu No Dust Allowed

Following are a few suggestions for specific problems in the field of remote sensing of air pollution which deserve additional attention, and suggestions for accomplishment of the studies.

- I. Problem: Development of the capability to process, quantify, and distribute information from available remote sensors at a central point for user convenience.

Through the cooperative efforts of several universities and governmental agencies (e.g., Purdue University, University of Michigan, National Air Pollution Control Administration, NASA-MSC) technology, hardware and software have been developed to maximize the useful information that can be retrieved from remote sensor information. Examples of this capability include software for data processing as done with the LARS program, separation of emulsions for recovery of signature data from color film, coding and digitizing of photo-imagery.

Although this capability does exist it is dispersed throughout several organizations. With the recognition of the earth oriented problems which might benefit from the ability to gather data utilizing remote sensors the need of investigators for data processing capabilities will grow. In effect, the inability to furnish investigators the type of information requested can limit the growth and usefulness of the entire field of data acquisition utilizing remote sensors.

Work Proposal:

1. Identify all different methods developed for retrieving data from photo-imagery and scanning imagery.

2. Locate the experts for all such methods and discover whether facilities exist for routine data retrieval.
3. Identify and list the requirements necessary to bring the method to the state of routine operation.
4. Identify the types of problem areas or applications previously associated with each method.
5. Determine the probable work load for each method.

Budget: Annual

Personnel

Investigator	\$24,000.00
Clerk Typist	6,000.00
Travel Funds	2,000.00
Office Equipment	500.00
	<hr/>
	\$32,500.00

II. Problem: Demonstrate the feasibility of locating point sources of air pollutants. This may be done utilizing photo-imagery or multispectral band scanning spectrometers.

Suspended particulates of gross concentration are easily detected in pictures from space platforms viewed by an observer. In effect the reflected energy in the visible spectral band, scattered by particulates, yields a detectable, recognizable signature. Since most gaseous air pollutants do not absorb, reflect, or emit electromagnetic energy in the visible spectral bandwidth they cannot be detected in that region of the spectrum.

However, it is well known that these vapors absorb energy at unique bandwidths in the infrared.

The Bendix M₂S or the University of Michigan multi-spectral, 24-channel scanning, imaging spectrometer are available as detectors.

Work Proposal:

1. Identify possible point sources of pollutants by imaging the detected energy in the thermal spectral band, 8-14 μ .
2. Correlate high energy areas with identified ground sources, e.g., chimney stacks or open fires.
3. Check with local Air Pollution Control Administration for a list of sources indicated in their "Emission Inventory".
4. Indicate the number of sources revealed by both methods that are similar, dissimilar. Classify the sources by output.
5. Estimate the sensitivity and limits of detection.

III. Problem: Demonstrate the feasibility of locating point sources of specific air pollutants, e.g., sulphur dioxide, nitrogen oxide, ammonia.

This should be accomplished in a similar manner to Problem II, but utilizing specific infrared absorption bands.

Budgets for Programs II and III
would be similar to Program I

4. WATER POLLUTION

To effectively manage our supply of surface waters, it has become increasingly apparent that more rapid and efficient means of detecting and quantifying water pollution are required. Requirements for these resource management efforts all too often have been demonstrated to be clearly beyond the capability of even combined local, state, and federal agencies. Additionally, the routine quantification of surface water quality has become a necessity in certain geographical areas due to population density increases as well as point location of industrial outfall sources. From a public health viewpoint it would not only be desirable, but appears to be a necessity to approach the problem of surface water quality management by other means than the laborious, yet quantitative methods of laboratory analyses now available. As yet, rapid assessment by any other means has proven to be semi-quantitative (with regard to need). One of the most promising areas appears to be that of applying remote sensing response interpretation to aquatic resource management.

Application of these principles has directed itself to the development of other than simple aerial photography. Selectively sensitive photographic film has been developed and, to a great extent, perfected insofar as its spectral response is concerned. The problem remains as to the relationship between the imagery produced by exposure and the actual aquatic content.

Currently, water pollution technology relates its capability to the interpretation of physical, chemical, and biological data derived from specific qualitative or quantitative tests of that environment. Further categorization of the chemical tests would divide the group of parameters into organic compounds, inorganic compounds, ions, and/or molecular parameters. Increasing legislation in the area of establishing standards for many parameters in those categories further emphasizes the need for more advanced technology in relation to their measurement.

Naturally the more grossly polluted bodies of water are the more easily recognized by test as well as, in some instances, by one or more of the senses. On the other hand, the more subtle forms of pollution may require identification of the source as well as taxing the limits of resolution of even the most advanced electronic laboratory apparatus. Therefore, the differences between the quantities of added materials in the least polluted and the most highly polluted waters are dependent on measurement of pre-selected parameters, all of which have limits of detection. Some of the specific parameters which are classed in the physical, chemical, and biological groups of parameters commonly interpreted in pollution evaluation or the determination of water quality are the following:

Physical -

pH, temperature, specific conductance, turbidity,
salinity, color.

Chemical -

Inorganic: heavy metals, alkalinity, hardness, nitrogen compounds such as ammonia, nitrite, nitrate, chloride, phosphorus compounds, sulfates, sulfides;

Organic: Biochemical oxygen demand, chemical oxygen demand, organic carbon, oils, greases, synthetic detergents, methylene blue active substances, phenols.

Biological -

Higher aquatic plant growths plankton densities, bacteriological quality, fish populations.

Some of the imagery which has been developed for use in remote sensing or which was developed previously and put to use in remote sensing practices has employed photographic film. Image responses have been recorded by black-and-white, thermal infrared, color, and color infrared film. It appears that each of these types is capable of recording one or more parameters in the hydrosphere. Combinations of two or more of these types afford cross-evaluation of more than one aquatic parameter. Naturally, limitations are inherent to each film type.

Quite often filters are used with some of the films to sharpen the image or, more directly in some instances, to produce an image. Since the overwhelming majority of film responses are due to emission and/or reflectance characteristics of the water, one limitation has been depth perception.

Black-and-white imagery has proven useful in area evaluations and for such endeavors as shoreline demarcation, detection of the point of the forward edge of tidal movement, and other measurements which are dependent on differences in the black-and-white densities varying from black to white.

Natural color imagery has been applied with limited success only because of the development of more sophisticated responses in films. Generally, high altitude responses of natural color imagery are less meaningful than lower altitude responses because of atmospheric content interference with the natural color response mechanisms of the film.

Color infrared film has been used quite successfully in several applications in combination with filters. Attempts have been made to identify or quantify some of the aforementioned physical, chemical, or biological parameters directly using color infrared imagery. The results of those attempts have led to further attempts to quantify some of the parameters indirectly. By way of example it is well established that certain aquatic species of higher plants grow or are tolerant of distinguishable salinity ranges. Some of these ranges, from freshwater to saltwater, and a few of the plant species are:

Freshwater (0 - 3° / ‰ S) -

Nuphar advena (yellow-pond lily), Zizania aquatica (wild rice), Pontedaria cordata (pickerel weed);

Brackish water (3 - 10° / ‰ S) -

Phragmites communis (reed), Spartina cynosuroides (Saltmarsh reed), Typha angustifolia (cattail);

Saltwater (10 - 35° / ‰ S) -

Spartina patens (saltmeadow grass), Spartina alterniflora
(Saltwater cord grass), Iva frutescens (marsh-elder)
Juncus roemerianus (needle rush).

Limitations on the color-infrared responses in this area of plant species identification include the area size in which the submergent or emergent vegetation exists and whether or not more than one species is present.

Color infrared film seems to be useful in combination with the Wratten 61 and 89-B filters in plant species identification attempts and in distribution and shoreline delineation. The Wratten 15-G is the filter which is generally useful with color infrared imagery but is exceeded in its capability by the Wratten 25-A in capability to sharpen the image response of submerged aquatic plants. At altitudes exceeding 15,000 feet color infrared imagery is superior to natural color imagery.

In measuring the reflectivity of three species of aquatic plants (Zizania sp., Nuphar sp., Juncus sp.) Anderson (5) reported that the spectral reflectivities were similar in curve shapes but varied slightly in their magnitude. In the visible range (0.4 - 0.7 μ) the following relationships held for the three species:

<u>Reflectivity Variance</u>			<u>Band</u>
1	-	6%	Between 0.4 and 0.5 μ m
6.2	-	7.1 %	at 0.55 μ m
3.3	-	6.7 %	at 0.675 μ m

Some seasonal difference in reflectivity response signature was also reported for Phragmites sp. (reed) for the months of July and October. In all cases the greater differences in magnitude in reflectance

versus wavelength occurred in the 0.7μ to 1.3μ region. Additional information was furnished for the $0.7 - 0.9\mu\text{m}$ region as follows:

<u>Plan</u>	<u>Tonal Signature on Color IR Film</u>	<u>Avg. Reflectance $0.7 - 0.9\mu\text{m}$</u>
Cattail	Dark	29.2
Pickerelweed		31.1
Sweet Flag		29.7
Wild Rice		29.4
Salt Marsh Grass		23.9
Yellow Water Lilly	Light	32.3

Quantification attempts at water depth have been significantly enhanced by development of multispectral scanning devices. Polcyn (6) achieved greatest penetration in the blue and blue-green ranges. These data appear to conflict with earlier reports. A summary of his findings are the following:

<u>Wavelength Band</u>	<u>Description of Penetration Ability</u>
$0.40 - 0.44\mu$	fair penetration
$0.50 - 0.52\mu$	excellent penetration
$0.55 - 0.58\mu$	excellent penetration
$0.62 - 0.68\mu$	only shallow features distinguished
$0.80 - 1.00\mu$	no penetration; only broad shoreline and water demarcation

It was suggested that at least two channel responses should be examined to obtain the most reliable result. The following equations were

developed to this end:

$$V_{\lambda} = K_{\lambda} P_{\lambda} H_{\lambda} e^{-\alpha_{\lambda} Z (\cos^{-1}\theta + \cos^{-1}\phi)}$$

$$Z = \frac{1}{f(\theta, \phi)} \ln \frac{V_{\lambda_1} K_{\lambda_2} P_{\lambda_2} H_{\lambda_2}}{V_{\lambda_2} K_{\lambda_1} P_{\lambda_1} H_{\lambda_1}}$$

$$(\alpha_{\lambda_2} - \alpha_{\lambda_1})$$

where:

λ_1, λ_2 = extinction coefficients of water at two wavelengths.

P_1, P_2 = bottom reflection in two different bands.

K = constants of instrument which are known.

H = incoming solar radiation measured by sun sensor on aircraft.

V_1, V_2 = voltages; analog signals observed in the multispectral scanning of the shallow features.

Although it is believed that this is a positive step in approaching this subject, several value descriptions were not included in the definition of the equations' terms, e.g., values for theta and rho and units of solar radiation.

Using a spectrometer and its resulting imagery, White(7) attempted correlations between Secchi disc readings, sewage concentrations, phytoplankton pigment concentrations, and wavelength responses with some success. Some of the recognized drawbacks to this approach are natural atmospheric and aquatic interferences. At shorter wavelengths of the spectrum particles in the atmosphere, for all intents and purposes, effectively reflect a high percentage of the useful measurable signal. A similar effect has

been observed for water itself. At longer wavelengths water molecules themselves scatter radiation; a natural and well-known characteristic. Similarly, the atmosphere is capable of absorbing much of the measurable signal at longer wavelengths. By way of example, at wavelengths greater than 0.7μ the absorption coefficient of water is of such an order of magnitude that any signal from beneath the surface never reaches the surface. One spectral region was cited as being the only one which is useful in making measurements of pollutants beneath the surface: $0.38 - 0.70 \mu$. The basic normalized equation used in the studies was

$$K = \frac{R_{\lambda_1} - R_{\lambda_2}}{R_{\lambda_1}}$$

where "K" values were plotted against Secchi disc penetration (ft.) and

R_{λ} = reflectance at stated wavelengths.

Clear water values for "K" were described as having been determined previously and were equivalent to values of "K" at Secchi disc depths of about 50 feet.

For aquatic measurements, emphasizing saline water environments, James (8) related the following observations from individual data as well as prior reports. Some of these observations may appear to contradict earlier reported factors as well. For maximum penetrability in deep ocean waters the 0.480μ wavelength achieves best resolution. In turbid coastal waters, greatest penetration can be obtained at the 0.530μ wavelength. Film responses vary by the built-in response of each type.

Panchromatic film is sensitive to the 0.400 - 0.700 μ region. Orthochromatic film responds with greatest sensitivity in the green region. It was stated that this type could be used for "depth studies", however, no defense was offered for this statement. Orthochromatic film was alleged to be most useful when used with a yellow filter. Infrared film records, with aid of a filter, in the 0.700 - 0.900 μ region, recording principally reflected energy. An earlier research effort involving use of an ultraviolet bandwidth was cited: 230 μ absorbance supposedly was related to sewage content in membrane filtered water. At this point it would be well to remember that ultraviolet bands characteristically demonstrate high atmospheric absorbance and/or interference. Regarding depth and infrared penetration, it was found that 90% of the light was returned toward the surface from the upper 1/2 meter in the infrared region. In comparing a waste concentration of from 0 to 30 ml/l with depth in meters, the plot was horizontal; specifically the 90% reflectance occurred from the upper 1/2 meter over the entire waste concentration range.

Color infrared response has shown promise as a tool which can be used for interpretation of features such as those outlined in the following table:

Table 4. Potential Information Which May be Interpreted From Color IR Photography of Marshlands and Estuaries

Feature	Interpretation Signatures
Water Salinity	Vegetation Composition Estimation
Water Turbidity	Light tone - more turbid. Tone evaluation
Nutrient Pollution	Aquatic plant species and phytoplankton blood density estimation
Water Currents	Bottom profiles, distribution patterns of suspended materials

Table 5. Potential Information Which May be Interpreted From Color IR Photography of Marshlands and Estuaries

Feature	Interpretation Signatures
Aquifers	Identification of associated plant life
Mudflats	Tone evaluation
Plant Species	Tone, pattern, spatial distribution
Submerged Vegetation	Tone evaluation. Species identification not possible

Interpretation of data presented by these responses by color IR has been largely qualitative.

Although pollution loading has been measured by several detailed analytical techniques, most of which deal with organic constituents, either water quality parameters are also due consideration from an investigative point of view. Parameters usually considered in the overall water quality and pollution assessment network along with an indication of positive attempts which have been conducted on each cited parameter follow:

Table 6. Water and Wastewater Parameters Positively Measured and Possible Imagery Response Interpretation

Parameter	Possible Remote Sensing Imagery Interpretation			
	UV	IR	Multispectral	Unknown
Heavy metals				X
pH				X
Temperature		X		

Parameter	Possible Remote Sensing Imagery Interpretation			
	UV	IR	Multispectral	Unknown
Conductivity; salinity			X	
Dissolved gases (O ₂ , H ₂ S, CO ₂ , etc.)				X
Turbidity		X		
Inorganic quality levels:				
Alkalinity				X
Hardness				X
Chloride		X		
Nitrogen (NO ₂ , NO ₃ , NH ₃)				X
Phosphates	X			
Sulfates				X
Organic quality levels:				
Biochemical oxygen demand		X		
Chemical oxygen demand		X		
Organic carbon		X		
Oils, grease		X		
Detergents, MBAS		X		
Pesticides				X
Phenols				X
Color				X
Bacteriological				X

It would appear that reflectivity and organic composition show the greatest promise of those parameters cited for future applications.

Some of the specific areas which have been investigated and their regions of response are summarized in the following table:

Table 7. Areas Investigated and Regions of Response

Investigated Parameter	Possible imagery response region to be utilized for measurement
Underwater feature	Selected bands within 0.41 to 0.60 micron
Oils, urea, phosphate fluorescence	0.28 to 0.31 micron
Algal concentrations, chlorophyll-a, organic content	0.75 to 0.90 micron
Oil slick	appears lighter than surrounding medium at 0.32 to 0.38 micron
kelp	0.8 to 1.0 micron (appears lighter than bkgnd.) 0.32 to 0.38 micron (appears darker than bkgnd.)

Selection of specific bands might suggest the need for multispectral response analysis for quantification purposes.

Thermal infrared response has proven to be effective in identification of thermal discharges, the area of influence of the discharged water, and only to a limited extent, the temperature differential.

TABLE 8.

PUBLIC HEALTH ECOLOGY (WATER POLLUTION) PARTIAL
SUMMARY OF OBJECTIVES AND REQUIREMENTS

Application	Phenomenon	Characteristic	Detector	Resolution Meters	Spectrum	Resolution
Surface Waters	Organic Pollution	Sewage	IR	to 1 M@ 1000 ft.	Multi- spectral	to \pm 0.2 micron desirable
		Organic Indus- trial Waste	IR	"	Multi- spectral	to \pm 0.2 micron desirable
	Inorganic Pollution (Incl. Heavy Metals)	Factory Waste	Color IR Multi- spectral	to 1 M@ 1000 ft.	Selective band width	Unknown
		Run-Off	Multi- spectral	"	Selective Character- ization re- quired	Unknown
Pesticides	Industrial Discharge	B&W IR		to 0.1 M@ 500 ft	Unknown	Unknown
		Multi- spectral				
	Run-Off					
Estuaries	Organic Pollution of Beaches & Shellfish Beds	Sewage	IR Multi- spectral	to 1 M@ 1000 ft.	Carbon lin- eage Charac- terization	to \pm 0.2 micron desirable
		Organic Indus- trial Waste	IR	"	"	to \pm 0.2 micron desirable
		Red Tides	IR and Multi- spectral	to 1 M@ 1000 ft.	0.60 to 0.90 micron	to \pm 0.001 micron desirable
	Plankton Growth					
Destructive Effects	Read Fish & Other Organ- isms		Color IR B&W High Contrast	to 1 M@ 1000 ft.	70.8 micron, etc. after individual Character- ization	desired resolu- tion

Exact quantification of the temperature differentials between the receiving waters and the effluent waters is an area which certainly requires more research input. Emission of the thermal energy and recording of same is limited thus far by a naturally occurring phenomenon. The first 0.02 millimeter of the water's surface is 0.6 to 1.0 degree (Centigrade) cooler than the water immediately below it, due to evaporative cooling mechanisms. Herein lies the problem in which the reflectance and emissivity spectra are recorded. Corrections have been used in the quantification attempts based on blackbody emissivity. Emissivity is defined as the ratio of the amount of radiation emitted by a body at surface temperature to the amount of radiation emitted by a blackbody at the same temperature. Water at near 0°C. characteristically possesses an emissivity value of 0.993.

Essentially, imagery of the earth's surface, whether it be terrestrial or aquatic, is a two-dimensional reproduction of the relative intensity of electromagnetic radiation emitted from the surface in the 8 to 14 μ range (approximately, for infrared, by way of example). This bandspread has been dubbed the "atmospheric window" in which the absorption characteristics radiation of water vapor, and compounds such as carbon dioxide, are minimal. It would be beneficial to recall the Stefan-Boltzman Law at this point. Summarily, the intensity with which energy is radiated from an object is proportional to that object's absolute temperature raised to the fourth power. It is also directly proportional to the emissivity. Standard black-and-white positive films therefore appear lighter in regions where higher radiation and/or emissivity occur.

Recently more advanced remote sensing hardware has been developed which shows promise in the application to water pollution assessment and resource management. A few of the more recent additions include the following instrumentation.

Remote Sensors

<u>Sensor</u>	<u>Spectrum</u>	<u>Format</u>	<u>Resolution</u>	<u>Field of View</u>
RS-14 Dual Channel Infrared Scanner	0.3 μ to 0.55 μ or 3.0 μ to 5.5 μ and 8 μ to 14 μ	70mm Film Magnetic Tape	3 ft. @1000 ft. altitude 1 milliradian (MR) or 3 MR	80° (Scan Angle) Instantaneous: 1 MR or 3 MR
Rapid Scan Spectrometer	6.715 μ to 13.325 μ	Magnetic Tape	2 Meters @ 1000 ft. Altitude	0.4° x 0.4°
Infrared Radiometer System	10.375 μ to 12.1 μ	Magnetic Tape	2 Meters @ 1000 ft. Altitude	0.4° x 0.4°
Precision Radiation Thermometer (PRT-5)	8 μ to 14 μ Multi-spectral Analyzer 0.5 μ to 13.0 μ	0-5 Vdc ---	0.5°C ---	2° ---

Future Direction of Effort - As the technology advances in instrumentation development as well as in expertise enhancement, the following projects should be considered as primary concern to the realization of the overall goal of surface water quality management.

1. Full development of spectral responses of existing sensors is required.
2. Further identification is required of the depth penetration capabilities of each sensor,

their capability to identify plant species, and delineation of areas of existence of the plant species in question.

3. Discharge points, quantification of discharged materials and quantities need full evaluation.
4. Responses must be catalogued for each of the above units (plants, soil types, discharge contents, volumes, and quantities), these should then be correlated with such factors as season-of-the-year, ambient temperature, atmospheric conditions, and other pertinent factors.
5. Natural ecological changes contrasted to resource development such as river basin or estuarine "Development".
6. Identification of the requirements for frequency of sensing, i.e., seasonal, monthly, daily, or hourly. Instantaneous responses can be effective only in limited instances.
7. Night sensitiveness quantification.
8. Altitude response and parameter quantity qualification must be identified.

Thus far the area of remote sensing has proven feasible in water surveillance with limitations due to the inherent capacities of the response imagery and to the lack of adequate groundtruth data in many instances. There is no doubt that future attempts to correlate the two will yield more useful results. Further, the second generation

of more sophisticated sensors stand a good chance of improving the response meanings over the film image response by regular camera photography.

Most of the dissolved and/or suspended inorganic, and to a great extent, organic ions and molecules are as yet undetectable in water. With newer techniques evolving and with response reproduction becoming more sophisticated, more meaningful interpretations will evolve. We must utilize other areas of the known energy spectrum such as ultraviolet bands. With the advent of multispectral and radar imagery, an increase in the capability of remote sensing of surface waters was greatly enhanced.

The multispectral scanner incorporates a response capacity from 0.34 through 1.30 microns. Since many pollution parameters (BOD, COD, MBAS, and, for example, oil slicks) are basically organic in constitution, this scanner shows promise by virtue of its selectivity of response bands. Some proven responses and some under investigation with selective response regions and the corresponding investigated parameters are the following: Submerged feature, bands within 0.41 to 0.60 micron range; Oils, urea, phosphate fluorescence, 0.28 to 0.31 micron range; Oil slick, lighter hue than surrounding medium in 0.32 to 0.38 micron range; Kelp, lighter than background in 0.8 to 1.0 micron range. Darker than background in the 0.32 to 0.38 micron range; Chlorophyll-a, algal concentrations, organic content, 0.75 to 0.90 micron range.

Late arrivals in the sensor field which can be applied in the surface water reconnaissance area include the RS-14 scanner which

has the capability of responding in the 3.5 to 5.0 micrometer and 8.0 to 14.0 micrometer ranges and the PRT-S Precision Radiation Thermometer which possesses the capability to respond to surface temperature between -20° and $+40^{\circ}\text{C}$ in the 8 to 14 micrometer region.

In the area of surface water aerial remote sensing reconnaissance it has become increasingly apparent to the point of obvious insistence that rapid identification of parameters in question be resolved in regard to appreciable surface areas. In this light it is essential that the full capability of each sensing instrument and/or technique presently known be developed to the fullest extent. Not only must the applications be established but, more importantly, the limitations should be recognized and established.

For each parameter under investigation the frequency of "sampling" via remote sensing should be established. Season-of-the-year will suffice in certain instances but will be of far too long an interval duration in others. The benefits which can be obtained from further development of all of the remote sensing capabilities are immense. It is not outside the realm of possibility that entire resource management programs could be directed from the results obtained by overflight response. There are no geographical limits to this. River basins and the effects imparted to the ecosystem by their development, estuarine management and pollution control, and area resource evaluation, whether terrestrial or aquatic, are just a few of the important contributions which can be achieved by remote sensing activities.

Specific budgeted suggestions for this additional work have not been developed as yet. It is obvious that the eight points developed will require a major effort.

5. COMMUNICABLE DISEASE

From the outset of the project there have been a number of environmentally related human disease conditions which seemed to be amenable to remote sensing, particularly certain vector-borne diseases, such as sylvatic plague and onchocerciasis. However, it was equally obvious that any approach used would be quite indirect. In the case of disease conditions of crops or forests one may expect to see the effects directly, by detection of changes in color in the visual or near infrared range. Certainly this will not be true of all disease conditions, but some of the more important, such as corn blight, or gypsy moth damage can certainly be detected. In the case of human diseases one certainly cannot expect to deal with directly observable changes. The emphasis instead is on the determination of the environmental changes which promote human disease (such as fecal contamination of the surface water supplies) or which promote the production of the vectors of disease (such as plants associated with certain mosquito larval habitats). None of this presents an insuperable problem, but it does impose the strict necessity for detailed knowledge of the biologies and ecologies of the vector/organism/host relationships which simply are not available for most of the disease, and hardly suitable for some of the best studied diseases.

In order to be sure that all of the possible diseases of interest were considered the project personnel used the following publication

as a guide to diseases to be considered: "The Control of Communicable Diseases in Man", Abram S. Benenson, Ed. 11th Edition, 1970. The results of this survey are presented in the following section. The initial plans, progress and reports of several other major U.S. Government supported projects were also examined during the course of this survey: The Mapping of Disease (MOD) project of the Armed Forces Institute of Pathology, and the information retrieval system operated by the Department of Entomology, Cornell University for the U.S. Army Quartermaster Laboratory, Natick. The MOD project would have had a considerable interface with the type of remote sensing studies discussed here, but unfortunately has been terminated. The Cornell project mapped disease vector distribution, but depended entirely on published material and plotted distribution on a continental scale, only indirectly reflecting the ecological considerations involved. The only project known to be operating at present which might be meshed with remote sensing activities in a meaningful manner is the computerized serological survey operated jointly by the Middle America Research Unit and the Institute for Nutrition - for Central America and Panama, which is discussed further in this section.

Table 9. Diseases listed in Control of Communicable Diseases in Man, APHA, but eliminated as unlikely prospects for remote sensing applications.

Actinomycosis	Hydatidosis
Angiostrongylosis	Influenza
Arbovirus ^{1.}	Keratoconjunctivitis
Balantidiasis	Larva migrans
Bartonellosis	Leprosy
Brucellosis	Listeriosis
Candidiasis	Lymphocytic choriomengitis
Capillariasis	Lymphogranuloma venereum
Carditis, viral	Measles
Cat-scratch fever	Meningitis, aseptic
Chancroid	Meningitis, meningococcal
Chickenpox	Mononucleosis infectious
Conjunctivitis	Mucomycosis
Cytomegalic inclusion	Mumps
Dermatophytosis	Mycetoma
Diarrhea	Nocardiosis
Diphyllobothriasis	Paragonimiasis
Dracontiasis	Paratyphoid
Enterobiasis	Pediculosis
Food poisoning	Pinta
Gonococcal disease	Pleurodynia

Granuloma inguinale

Hepatitis, viral

Herpangina

Herpes

Rabies

Rat-bite fever ².

Relapsing fever

Respiratory disease, viral

Rheumatic fever

Rickettsialpox ².

Rubella

Salmonellosis

Scabies

Smallpox

Sporotrichosis

Staphylococcal disease

Streptococcal disease

Syphilis

Pneumonia

Poliomyelitis

Psittacosis

Q fever

Taeniasis

Tetanus

Toxoplasmosis

Trachoma

Trichinosis

Trichomoniasis

Tuberculosis

Tularemia ³.

Typhus, murine ².

Typhus, epidemic

Whooping cough

Wolhynian fever

Yaws

1. There are over 200 arboviruses now described in varying detail; but for the vast majority of these the ecological data are far too scant to permit comment. Those which are considered further are listed in Table 13.

2 Presumably a number of rat-borne diseases of urban areas are related to numbers of rodents, which in turn may be related to housing quality. However, the relationship appears to be too tenuous to permit analysis.

3 Partially vector and water-borne, primarily contact.

Disease organisms not included in Table 9 have been covered in a number of categories, depending on their ecological associations. The first category considered includes those associated with the soil. These are listed in Table 10. Specific projects are suggested for three general categories: the intestinal helminths (ascariasis, ancylostomiasis, strongyloidosis and trichuriasis), for anthrax, and for one of the mycoses (coccidiomycosis) whose ecology is reasonably well understood. The other mycoses, and a few not listed, do not seem as promising for remote sensing application.

Table 10. Soil-borne diseases; contracted by inhalation, ingestion or penetration

Ancylostomiasis	penetration
Ascariasis	ingestion
Anthrax	inhalation, contact
Blastomycosis	inhalation
Coccidiomycosis	inhalation
Histoplasmosis	inhalation
Strongyloidosis	penetration
Trichuriasis	ingestion

Intestinal Helminths - The effect of environmental factors on the distribution of common intestinal helminths of man, namely hookworm,

ascaris, strongyloides and trichuris, is poorly understood. This question has received relatively little attention in the past three decades. Although the practical applications are limited, if it were possible to predict with remote sensing the distribution patterns of these parasites, it is felt that an attempt to do so is justified for the following reasons:

1. The effect of the environment on these agents is of considerable academic interest, and remote sensing may offer a more appropriate and convenient means of establishing associations between the presence of a parasite and specific environmental parameters (or combination thereof) than available from ground studies.
2. Considerable "ground truth" data on the distribution of human infection with these parasites is currently available from many parts of the world. The INCAP data bank offers a unique source of data of this type from some 200 communities in Central America and Panama. Less extensive data is also available in Puerto Rico.
3. The value of remote sensing as a tool to measure the distribution of human disease would be enhanced by demonstrating its ability to predict distribution patterns of these common intestinal parasites.

Examples of application

Following is a list of environmental factors thought to be related to the survival and transmission of egg and larval forms of these parasites.

<u>Characteristic</u>	<u>Relationship to Parasite</u>
Soil porosity	Affects migration of hookworm larvae
Soil moisture	Egg survival; trichuris especially susceptible to dessication
Density of peridomestic shade cover	Related to soil moisture
Soil salinity, pH	Egg and larval survival
Agricultural practices	Certain crops tend to favor occupational transmission
General sanitation	Potential soil contamination

Available technology

Panchromatic photographic film, multispectral sensing, and perhaps radar may be useful in defining soil characteristics. Amount of shade-producing vegetation may be best estimated with near infrared.

Proposals for work

1. Utilize existing ground truth data on prevalence of human infection with a given parasite, e.g., hookworm.
2. Choose environmental categories to be measured by remote sensing and define subjective grading system. (For example: unfavorable = 0; intermediate = 1; favorable = 2).
3. Using data obtained remotely, predict the rank (from low to high prevalence) of a number of communities (approximately 20).

4. Using the Spearman rank correlation test, compare the remotely determined ranking with results of parasitic surveys in these communities.
5. More elaborate and objective approaches could be developed if initial impressions were promising.

It is difficult at this point to propose an organization to do this type of study, or an appropriate budget. The incidence of all of these diseases is higher in tropical and semi-tropical areas where a low standard of living leads to pollution of the soil.

Anthrax - The spore-forming Bacillus anthracis which cause this disease have rather well defined ecological requirements, which have been described recently by Van Ness (9). A number of soil types have been recognized which are capable of supporting B. anthracis. The disease occurs in man at present primarily in well defined industrial epidemics among those handling hides, wool or other animal products which have been contaminated. The indirect effects are perhaps more important. That is, the loss of livestock may be a serious economic loss, and in developing countries may cut down on an already meagre supply of protein.

Van Ness and other workers have indicated that anthrax survives nature in "incubator" areas which are characterized by a pH higher than 6.0, and an ambient temperature above 15.5°C. The coastal soils of Texas and Louisiana, with high concentrations of calcareous materials and organic matter. At present the Public Health Ecology Section, MSC is cooperating with the National Center for Disease Control, Louisiana

State Health Department authorities and others in a study of a recent outbreak of anthrax in cattle in Ascension Parish, Louisiana. A 1971 epizootic in the Parish resulted in the deaths of over 500 cattle and other livestock. The cases were not evenly distributed, and appeared to confirm the concept of incubator areas advanced by Van Ness and others. Several missions have already been flown and a map of the soil types in the areas with and without the disease are in preparation. As an additional task, attempts are being made to determine the number of large animals in the area by means of infrared spectroscopy (using the RS-14 system). Ground truth data are now being accumulated and compared with the remote sensing data.

This should provide an excellent test of the incubator area concept of anthrax. If the soil types are correlated with particular vegetational patterns, which seems very likely, it may be possible to identify the incubator areas over a large region by recognition of the vegetational signature. Color-infrared film alone may be sufficient to identify the areas rapidly, if the vegetational features are characteristic enough.

In view of the effort being expended by the NASA-NDCD and State of Louisiana in this project no further recommendations appear to be warranted. If the program in Ascension Parish is successful it should be extended to other geographical areas of the United States where enzootic foci occur and occasionally break out as epizootics - particularly in such diverse areas as southern Florida, California and Nevada.

Coccidiomycosis: This mycotic infection is very common in limited areas from Southern California to Argentina. In the arid regions of the United States it may be an important infection of military recruits and migratory workers. Infection occurs when the fungal spores are inhaled, suspended in the dust swirls which characterize hot arid areas.

There are a number of such mycoses, but coccidiomycosis is one which appears to have an associated biological marker which may be detectable by remote sensing. A number of workers have reported that areas of high risk for coccidiomycosis usually have significant stands of the creosote bush (Larvea tridentata). The strength of this association is not presently known, but one worker consulted during this project (Dr. R. Tesh, Middle America Research Unit) has had personal experience with the disease and believes that it is strong enough to warrant further examination. It has been shown that spread of the disease can be halted by such devices as the oiling of airfields and other open fields, and the planting of grass and other covers to reduce the contamination of the air. How practical this would be over a large area, or how much area is actually involved is unknown at this time.

Three federal agencies would appear to have interests in this type of research: The Department of Defense because of infection in recruits, the Public Health Service because of frequent infection in migrant workers, and the Department of Agriculture because of the involvement of agricultural practices, and the high infection rates in arid land cotton growing areas. The USDA Soil and Water Conservation Research Division station at Weslaco, Texas has been

using remote sensing techniques for some time, developing signatures for various plant types. In cooperation with clinicians and mycologists from the other federal agencies it may be possible for them to develop indices of danger of coccidial infection in a relatively short time, using in-house research personnel and funds. Therefore, no budget has been suggested for this project.

Histoplasmosis - This fungal disease also depends on inhalation of spores for establishment of the infection in man. Unlike coccidiosis, it is usually associated with areas heavily contaminated by animal feces (blackbird roosts, bat roosts, chicken houses, etc.). Remote sensing might be of some assistance in locating and plotting large blackbird roosts, either by detection of the higher than ambient temperatures generated by the huge flocks of birds, or more easily by aerial photography, with color-infrared film, of the damaged trees which occur when the birds roost in forested areas. This is a low priority suggestion, since histoplasmosis is so widely disseminated in nature that detection of one or several large sources in any given area may touch only a small part of the problem.

Water-Borne Infections - These include some of the most important human killers in the history of mankind. Fortunately many of these diseases (listed in Table 11) have tended to disappear in the recent decades, either because of the provision of adequately treated water supplies, and proper sewage disposal, or because of the development of effective vaccines. The problem of water-borne organisms persists,

however, in the developing nations of the world. We are seeing at present, in fact, a considerable extension of the range of cholera, particularly the El Tor hemolytic strains. Cholera cases have recently appeared as far west in Europe as Spain and France, and by all indications the disease is continuing to spread in response to environmental changes which appear to be unexplained at present. It is possible that the rapid movement of individuals by aircraft has played a significant role in this recent spread, but the disease has always been known to occur in periodic pandemics, with alternate shrinkage to Southern Asia.

Table 11. Diseases associated with fecal contamination of water.

<u>Disease</u>		<u>Mode of Entry</u>
Amebiasis	Protozoan	Drinking water
Cholera	Sectional	Drinking water
Diarrhea (various)	Mixed	Drinking water
Giardiasis	Protozoan	Drinking water
Fascioliasis	Helminth	Eating water plants
Chlonorchiasis	Helminth	Eating infected fish
Shigellosis	Bacterial	Drinking water
Typhoid fever	Bacterial	Drinking water
Schistosomiasis	Helminth	Penetration of skin

The detection of potential danger from any of the diseases listed in Table 11 would depend on detection of fecal contamination of water

supplies. This relates back to the section of this report dealing with water pollution. One element which should be mentioned is the fact that in most parts of the world where the fecal-water borne bacterial and protozoan diseases abound almost all water can be taken to be contaminated almost continuously, and the elements which cause periodic epidemics are not clearly understood. One member of the project staff (Dr. J.E. Scanlon) has worked extensively in endemic areas of cholera and amebiasis, and in these areas (East Pakistan in particular) the level of fecal contamination of the surface waters is so high that remote sensing would seem to offer no particular additional information.

In more developed areas outbreaks of water-borne disease, occur when the integrity of the water mains is broken. One large epidemic of amebiasis in the United States for example was due to a cross-connection in the plumbing of a large hotel. Under such circumstances remote sensing can hardly play a part. As noted, the whole of water pollution is covered in more detail in the appropriate section.

Schistosomiasis - In the case of schistosomiasis or snail fever the situation is different, and considerably more complex. These diseases involve an intermediate invertebrate host (usually a snail) which may have ecological associations which can be detected remotely. We will use schistosomiasis as an example, since it is by far the most important of these helminthic diseases, and perhaps the best studied.

Schistosomiasis is one of the most important human diseases in many tropical areas of the world. In Africa particularly it appears

to be spreading and growing in intensity, due largely to the increasing impoundment of large bodies of water for hydroelectric power and irrigation. Three species of schistosomes attack man, each having a series of snail hosts, and each of these in turn having certain ecological associations. The problems in Africa with this series of diseases may well be disastrous in the long run, but much still remains to be learned about the various ecological forms there.

In preparing this evaluation we have limited ourselves to the infection in the New World, specifically in Puerto Rico where it has been studied in great detail, and to the British Caribbean islands (St. Lucia). It is probable that most of the observations made below on Puerto Rico can be extended to Africa and the Far East with considerable overlap.

Biomphalaria glabrata is the principal intermediate host of Schistosoma mansoni in Puerto Rico and most of the Americas. This aquatic snail is found in a wide variety of freshwater habitats, most commonly in small streams. Typically, breeding occurs in relatively static water habitats, and periodic flooding of the breeding sites washes the snails into flowing waters, where most snail and human infection occurs.

Programs to control transmission of S. mansoni to man are based primarily upon efforts to reduce B. glabrata populations, for prolonged periods, in endemic foci where infected man and snail live in close contact. Snail control programs are faced with practical problems for which remote sensing techniques may offer

advantages over current approaches. This report attempts to define these specific problem areas, suggest remote sensing techniques appropriate for each problem, and outline approaches to evaluate the relative advantage (or disadvantage) that remote sensing offers over conventional methods.

Statment of Problem #1: Watershed Definition

In the preliminary stages of establishing control priorities for a large endemic region, it is important to define basic geographical or operational units. Since the inqermediate host of S. mansoni is aquatic, there are obvious advantages in basing these units upon surface water drainage systems (watersheds) rather than upon arbitrary political boundaries.

Example of application - Watersheds have been defined in Puerto Rico with 1 : 20,000 scale topographical maps. This method is subject to errors, however, as evidenced by the fact that watershed boundaries thus defined transect streams in some cases. Side looking airborne radar (SLAR) imagery offers the potential advantages of better definition of surface water drainage patterns (especially in densely vegetated areas) and usefulness under all weather and light conditions. This can be of particular importance in tropical regions with almost perennial cloud cover.

Available technology - SLAR

Proposals for work - The object of this work would be to compare the ease and accuracy of watershed definition using conventional topographical maps and radar imagery at approximately the same scale.

Statement of Problem #2:

Mapping of Flowing Water Habitats

Accurate and detailed maps of stream systems in an endemic region are essential prerequisites for successful snail control programs. All potential flowing water habitats must be mapped, the lineal measurement of streams determined, and each segment of a drainage system identified on a map such that field workers can identify it.

Example of application - The conventional source of information on drainage systems in many areas is 1 : 20,000 topographical maps. (Figure 1) For the purpose of developing field maps needed for snail control programs, stream detail is insufficient in the topographical maps, for lower order streams are not shown. The usual approach to "improving" the existing topographical maps is to laboriously walk and measure the stream system from the ground (Figure 2). It is suggested that remote mapping of the stream system may offer distinct advantages over ground methods, both in accuracy and cost.

Available technology - Near IR color film from aircraft platform (approximately 1 : 5000 scale).

Proposal for work - The nature of this work would be to compare conventional ground maps with remotely determined maps in terms of various parameters of accuracy. Suggested steps are:

1. Selected study area, ideally one for which ground truth map (Map A) is already available
2. Obtain near IR aerial photographs of the study area,

suggested scale 1 : 5000

3. Interpretation of these photos and preparation of drainage system map of study area (Map B) to include longest order streams with permanent or intermittent flow. Marginal vegetation patterns bordering low order stream beds, with or without water at the time of photography, should be readily identified with near IR color film. This should aid in definition of low order radicals.
4. Compare Maps A and B by the following drainage parameters:
 - a) drainage area
 - b) number of stream segments
 - c) length of stream networks
 - d) cost estimates

Statement of Problem #3:

Identification of Snail Breeding Sites Distant

From Flowing Water Habitats

One of the major problems encountered in snail control operations in certain localities is that streams treated with molluscicides often become rapidly repopulated with snails. It is felt that static water snail breeding sites such as swamps or seepage areas, more or less distant from the streams, frequently serve as important sources of snails or snail eggs which repopulate the streams. Snails and/or eggs

are washed by intermittent flooding from these breeding sites into the streams. Often the breeding sites are hundreds or thousands of meters from the streams, and are not found without laborious ground search.

Example of application - Caladium sp. is a broad leaf plant with a pan-tropical distribution. It is commonly associated with static and slow-flowing surface water, such as along the margins of small streams and in low lying alluvium-filled areas with intermittent or permanent flooding. This type of aquatic habitat is frequently populated with B. glabrata (Figure 3). It is felt that near IR color film can be used to remotely identify potential breeding sites of B. glabrata at considerable distance from streams under snail control. Snail control in these breeding sites would help prevent repopulation of snails in the streams after application of molluscicides.

Available technology - Near IR color film from aircraft (approximately 1 : 5000 scale).

Proposal for work -

1. Determine if Caladium sp. can be identified consistently from near IR color aerial photographs (approximately 1 : 5000 scale). After developing adequate ground truth experience with identification of Caladium sp. from photographs, define a study area and prepare Maps C and D from ground survey and aerial photographs respectively. Comparison of these maps by acetate overlays will offer an objective measure of the reliability of the technique.

2. If it is demonstrated that Caladium sp. can be identified consistently, photographs from an area of approximately 10 square miles around known B. glabrata positive streams should be monitored on a regular basis to quantitate snail populations and size distributions, and movement of snails from these sites to the streams should be studied to determine their contribution to repopulation of the streams.

In St. Lucia the snail/vegetation/stream associations appear to be slightly different from those in Puerto Rico. This situation has been investigated in detail by Jordan and his associates (10), and since work is still going on there, it may be possible to extend some of the observations proposed above for Puerto Rico to St. Lucia.

A tentative annual budget for additional ground truth work in Puerto Rico and St. Lucia follows. It is based on the assumption that a significant amount of ground truth work can be done in cooperation with the Tropical Disease Section, NCDC.

Annual Budget

Travel to Puerto Rico and St. Lucia for Two People	
	- \$742.00 Round Trip
Travel by Rented Motor Bike to Sites	
	- \$100.00
7 Days Per Diem for Two People	
	- \$490.00
	<hr/>
TOTAL:	\$1332.00

Rodent-borne disease - There are a large number of diseases of man which are zoonotic - that is, diseases which occur in cycles in non-human animals, but which can infect man when he comes in contact with them. Many of these involve wild or domestic rodents. A number of these are listed in Table 12.

Table 12. Some Diseases of Rodents Transmissible to Man

<u>Disease</u>	<u>Mode of Transmission</u>
South American Hemorrhagic Fevers (Tacaribe and Junin viruses)	Rodent excreta
Korean Hemorrhagic Fever	Unknown
Leptospirosis	Animal excreta in water
Melioidosis	Animal excreta in soil
Plague	Fleas*

* Plague might as readily be listed as an arthropod-borne disease

For many of these the basic ecological data are insufficient to judge the possibilities of application of remote sensing. In the case of Korean Hemorrhagic fever, for instance, the mode of transmission remains unknown, even though the disease is now known to be widely distributed from Korea to Maritime Russia, westward to Scandinavia. Melioidosis has appeared a number of times in troops in Southeast Asia, but the ecological associations are almost unknown.

Plague, however, appears to offer some possibilities for remote sensing - at least in some of its sylvatic forms.

Plague - Plague is primarily a disease of rodents. The urban, bubonic form, the Black Death of the Middle Ages, is associated with domestic rats of the genus Rattus and their fleas. Once the bubonic form has been transmitted to man it may be further transmitted man to man by the pneumonic route. Neither of these forms would seem to offer any interest for remote sensing, other than the relationship of housing quality to rat populations.

But, there is in many parts of the world, including the Southwestern United States, an underlying cycle in rodents. With some frequency epizootics sweep through colonial rodents, killing most members of the colony. There is always the danger that such epizootics will spill over into urban rodents and human populations. For this reason the World Health Organization Expert Committee on Plague has recommended that all nations with plague foci within their borders maintain surveillance on this situation. In the United States such surveillance is maintained by several State health agencies in the Southwest, and by the U.S. Public Health Service Laboratory at Ft. Collins, Colorado. Surveillance over the rodents in areas where epizootics have been known is an expensive and difficult matter, but in the colonial species at least there may be some possibility of utilizing remote sensing.

Many of the recent epizootics have been in prairie dogs, which construct "towns" which may extend over many acres and contain thousands of individuals. The animals burrow constantly, depositing

fresh spill in mounds at the burrow entrances. They also maintain a series of paths free of vegetation by their activity. When an epizootic strikes there should be relatively rapid changes in soil texture, and even in dry localities a slower but marked change in the vegetation.

Project personnel have obtained a list of the exact localities of a number of prairie dog colonies, and attempted to find existing aerial photography of such sites in MSC files. No satisfactory imagery was located. In addition, contact was made with the Plague Section of the U.S. Public Health Service Ecological Investigations Laboratory, and they expressed an interest in further examination of this question, indicating that their budget for 1972 would not support work in this area.

In view of the extensive work which the USPHS has conducted in the ecology of plague it is strongly suggested that the Public Health Ecology section, MSC arrange to support that organization in further investigations in this field. They have plotted the location of a number of prairie dog colonies and when epizootics occur in one or more of them it should be possible to arrange for flights at a time when ground truth can be obtained by USPHS personnel. Specific elements to be examined are:

Appearance of normal colonies

Instrumentation to detect changes in vegetation
(color, color-infrared film)

Instrumentation to detect changes in soil texture
(multi-channel)

Suggested annual budget:

Personnel - remote sensing specialist to be stationed	
at Ft. Collins	- \$15,000.00
Travel to field sites	- \$ 3,000.00
Supplies	- \$ 1,000.00
Technical Assistance	- \$ 6,000.00
	<hr/>
TOTAL:	\$25,000.00

Arthropod-borne Diseases - Because of the environmental requirements of arthropods it appears that several of the most promising public health remote sensing applications may involve vector-borne disease, particularly those transmitted by mosquitoes and other blood-sucking Diptera. It is perhaps somewhat ironic that a failure to match remote sensing technology to arthropod-borne disease investigations may arise not from the newness of space technology, but from our relative ignorance of the environmental determinants of arthropod populations - a subject with a much longer history. Even with the best studied of the arthropod-borne diseases, malaria, it is somewhat discouraging to discover how little we know about the environmental determinants of the vector populations and distribution. When control of the vectors depends on rather gross and powerful chemical methods such biological knowledge is not nearly as important as it becomes when control procedures depend upon more subtle methods such as genetic manipulation or the use of pathogens. We now appear to be entering an era of vector control in which much more detailed biological information will be essential - including the chemical features of the soil

and water which may influence plant cover, which in turn may limit vector populations.

It would appear that available remote sensing technology, primarily photography in various portions of the visual spectrum, may help identify the breeding sites of a number of species of mosquitoes, and that sensor developments now on the horizon may permit detection of more subtle chemical differences. With terrestrial arthropods, such as Tsetse (Glossina), soil moisture and texture measurements may indicate satisfactory breeding sites. Other applications are noted below. The total number of arthropod-borne diseases is very large, and only the most promising have been selected for discussion here (Table 13). In particular, it has been necessary to eliminate most of the arthropod-borne viruses, since so little is known of their ecologies.

Malaria - This is one of the greatest scourges of mankind, possibly having killed more humans than any other infectious disease. In addition to mortality, it has sapped the energies of nations, particularly in tropical and semi-tropical areas, and delayed economic development. With the discovery of the parasite and the vector role of Anopheles mosquitoes in the early part of this century great strides were made in eliminating the disease on the fringes of its distribution, largely through larval control, drainage and "bonification". Much ecological data was accumulated on the vectors, but with the advent of DDT in the 1940's the program emphasis shifted to eradication, based almost entirely on the single tool of house spraying with

Table 13

Arthropod-borne Diseases With Remote Sensing Possibilities

Disease	Vector	Habitat
WEE ¹	<u>Culex tarsalis</u> , mosquito	Irrigated fields, ponds, ditches
EEE (enzootic)	<u>Culiseta melanura</u> , mosquito	Freshwater swamps
VEE (enzootic)	<u>Culex (Melanoconion)</u> , mosquito	Limited swamp habitats, hummocks in Everglades, mangrove
(epidemic)	Mosquito species	Many oren water habitats
Yellow Fever (urban)	<u>Aedes aegypti</u> , mosquito	Containers
(jungle)	<u>Aedes sp. Haemagogus sp.</u> mosquito	Africa: banana plants; America: Tree holes
Dengue	<u>Aedes aegypti</u> , mosquito	Containers
SLE	<u>Culex quinquefasciatus</u> , mosquito	Polluted ditches, sewage ponds, log soakage pits
CE	<u>Aedes sp., Psorophora sp.</u> mosquito	Woodland pools
Filariasis, Bancroftian (urban)	<u>Culex quinquefasciatus</u> mosquito	Polluted ditches, sewage ponds, etc. (S.E. Asia)
Filariasis, Malayan	<u>Aedes sp., Mansonia sp.</u> mosquito	Freshwater swamps (S.E. Asia)

Disease	Vector	Habitat
Leishmaniasis (muco-cutaneous)	<u>Phlebotomus sp.</u> Sandflies	Jungle floor, Panama; association with certain trees (?)
Onchocerciasis	<u>Simulium</u> , black flies	Rapidly running streams of varying sizes (Africa, Central America, South America)
Malaria	<u>Anopheles</u> , mosquitoes	Highly variable, see Table
Scub typhus	<u>Leptotrombidium</u> , chigger mites	Open grassy fields, jungle margins and clearings (Japan, S.E. Asia)
Trypanosomiasis, American	<u>Reduviidae</u> , bugs	Sub-standard housing
Trypanosomiasis, African	<u>Glossina</u> , Tse-tse flies	River margins (West Africa); margins of vegetation in savannah and forest (East Africa)
Kyasanur Forest Disease	<u>Haemaphysalis</u> , ticks	Forested areas; India
Tick-borne Rickettsioses	Tick species	Limited forest areas where ticks, small mammals and man may interact; many areas of world.

- 1 The following abbreviations have been used in the table and at appropriate places in the text - CE-California encephalitis; EEE-Eastern equine encephalitis; SLE-St. Louis encephalitis; VEE-Venezuelan equine encephalitis; WEE-Western equine encephalitis.

chlorinated hydrocarbon insecticides. With the development of physiological and behavioral resistance to pesticides, the emergence of drug resistance in the parasites, and other technical and administrative problems there has been a return to certain fundamental studies in malaria control, particularly attacks on the immature aquatic stages - exemplified in an article by Wright et al. (11), which just appeared in the Annual Review of Entomology. Because of this, the opportunity to assess the use of remote sensing in monitoring larval populations appears to have a chance for consideration, whereas a few years ago it would have been rejected as irrelevant.

One of the other elements which has complicated anti-malarial campaigns is the rapid ecological changes wrought by the accelerating clearing of forested areas, creating of new hydroelectric and irrigation schemes, etc. which characterize many of the developing countries where malaria is endemic to holoendemic. This ranges from major population shifts, which may go almost undetected, to the practice of small family groups moving into virgin forest for shifting agriculture. It is often almost impossible to find and treat the small groups.

It therefore seems reasonable to look at three possible applications of remote sensing in the field of malaria control:

1. Detection and monitoring of Anopheles mosquito production by remote sensing surveillance and study of the aquatic habitats of the immature stages.

Comment: A list of most of the major Anopheles malaria vectors of the world is presented in Table 14 . It will be noted that all of these have rather specific habitat requirements, but that few have really unique features which are immediately seen as amenable to remote sensing. These may include A. sundaicus whose larvae are found in beach pools of a certain salinity in Southeast Asia. This important species shows rapid population shifts, due largely to the availability or non-availability of temporary beach pools. These have characteristic algal blooms and may well be detectable, since the blooms will not occur until salinity has been reduced to a certain level. The same may be true of albimanus and other Central American vectors.

Scanlon and Sandhinand (12) reported an apparent association of A. balabacensis, an extremely important jungle vector in Southeast Asia, with a particular species of palm which should be recognizable by signature of the crown in jungle settings. This apparent association may be due to the particular type of sandy soil favorable to both palm and mosquito larvae. However, nothing more has been done on this, and furthermore the finding of significant populations of the mosquito has in itself been an extremely difficult problem. Since the bromelliads which support the growth of A. bellator and other vectors in tropical America seem to favor certain trees (the imortelle, Erythrina sp.) it may be possible to detect the host trees. However, the strength of the tree-bromeliad association is not well delineated. Other examples will suggest themselves from Table 14 , but much more work needs to be done.

2. The monitoring of relatively large population shifts, land clearing, etc.

Comment: It would seem that such shifts, which are extremely important in the epidemiology of malaria and other diseases would be relatively easy to monitor from the ground, through normal census or other political enumeration schemes. However, anyone who has worked in tropical areas, particularly those in which deforestation has been taking place since World War II will testify to the fact that rather major shifts can occur (Thailand, Amazon basin, etc.) long before they reach the level of consciousness of governmental agencies charged with health related programs. Routine aerial photography, with relatively unsophisticated equipment could be extremely helpful in this matter.

3. Detection of isolated family or worker groups in the jungle.

Comment: One of the most characteristic forms of agriculture practiced by people in areas where malaria may be hyperendemic is slash and burn or shifting agriculture. Malaria eradication procedures have depended on being able to identify and locate every actual or potential malaria case in areas under attack. When this type of agriculture is practiced, or when people occupy temporary harvest huts at the edges of their fields away from settled villages the location of such individuals becomes a very difficult task. Recent work by the World Health Organization in Thailand, where one member of the project (Dr. J.E. Scanlon) made a site visit for

the United States Department of State in 1971, indicates that many of the failures of the anti-malarial program were due to these temporary population movements. In many cases these small groups are hidden from view by heavy jungle canopy - but almost invariably they maintain cooking fires. Based on NASA and other reports of application of infrared detection to finding very small germinal forest fires it should be possible to detect normal camp fires of these small population groups, and to plot them on maps. At present it requires extreme effort to find all of these groups by ground reconnaissance to permit examination and treatment of the individuals, including days of marching through jungle areas, or even in extreme cases in Southeast Asia the use of elephant transport. Even at that one is not sure of having found all of the groups in a given area - with the possibility of leaving pockets of malaria carriers.

Suggested program - It would be possible to study the larval habitats of many Anopheles species in the United States or other readily accessible areas. However, it is felt that wherever possible the situation should be studied in an area where an actual problem exists. There are two active malaria research programs which suggest themselves for components of remote sensing studies:

- a) Central America Malaria Research Station, National Communicable Disease Center. This would particularly be for study of A. albimanus, which has already occupied the attention of station personnel for

several years. Some aerial photographic work has been done on the "esteros" or lagoons which support heavy albimanus populations at times. The matter has been discussed with the Director, NCDC and with Dr. Jeffries, Director of the CAMRS in El Salvador, and Dr. Sencer has been briefed by MSC staff. Both have expressed interest. Recommend that they be asked to participate formally, and that their staff in El Salvador make the necessary ground truth observations on the Anopheles albimanus populations. If this suggestion is accepted the only expense would be a small number of trips to the study area for MSC remote sensing experts. It should be noted that CAMRS, although an arm of NCDC is financed almost entirely by the Agency for International Development, U.S. Department of State. The chief of the malaria section, AID has also been briefed on this matter by one of the project staff (Dr. J.E. Scanlon).

- b) The South East Asia Treaty Organization (SEATO) Medical Research Laboratory in Bangkok, Thailand, is one of the most active malaria research laboratories in the world. The Director and Chief of the Entomology Department have been briefed on remote sensing possibilities by one of us (Dr. J.E. Scanlon) during a consultantship for AID in Thailand in 1971. It would

be possible there to make additional observations on Anopheles balabacensis larval biology, and detection of the breeding sites by remote sensing, to follow changes in populations related to clearing of the jungle, and most important, to test the possibility of detecting small groups of humans in some of the most difficult jungle terrain in the world. The World Health Organization research team in Thailand has also been briefed and expressed great interest in remote sensing for the latter purpose. It is believed that most of the ground truth work could be done by cooperating U.S., Thai and WHO workers as part of their on-going projects and with relatively little added expense. An expert on remote sensing technique, and one familiar with the biology of A. balabacensis should make one or two trips to Thailand over a two year period, in different parts of the year. The U.S. Air Force maintains a large scale effort in Thailand, including massive aerial photographic commitments, and might be able to provide at least aerial photography with several films. They may possess other capabilities as well, and might make them available as a part of their "civic actions" program as a contribution in promotion of health.

Table 14.

Environmental Relations of Larvae of Major Malaria Vectors¹.

North America^{2,3}.

quadrinaculatus

Ponds, lakes, lime sinks; highly dependent upon emergent vegetation for shelter; lime content of usual sites may be helpful.

freeborni

Fresh seepages, rice field

aztecus

Wide variety of surface water containing abundant algae and protozoa. Heavy bloom might be detected.

Central America

albimanus

Small water collections, hoofprints, lagoons (partially heliophilic)

aquasalis

Brackish lagoons, marshes, irrigation ditches

punctinacula

Pools, swamps, sluggish streams; under shade

darlingi

Fresh marshes, lagoons, without vegetation; heliophilic

South America

bellator

Arboreal bromeliads in jungle trees particularly immature

Africa

gambiae

Freshwater pits, pools, puddles, sluggish streams, and peridomestic water

funestus

Swamps, stream margins, lakes, ponds, ditches and seepages

Indo-Persian

culicifacies

Pools, pits, wells, irrigation water, rice fields, riverbeds. Usually in fresh but tolerates brackish water

fluviatilis

Pools, foothill streams, springs, streambeds, irrigation channels, rarely edge of swamps, lakes, tanks; heliophilic

Indo-China, Malayan

minimus

Slow foot hill streams, springs, irrigation ditches, rice fields; heliophilic

maculatus

Stream and river beds, seepages, small pools, rice fields, ditches, lake margins

balabacensis

Shaded pools. Disappears when covering vegetation is removed

sundaicus

Brackish or salt water lagoons, swamps and pools, behind coastal embankments, tidal drains; heliophilic

cruzi

Arboreal bromelliads, usually shaded, often S.M. above ground

pseudopunctipennis

Clean seepages, pits, pools, streams, rich w/algae; heliophilic

Palearctic (North Europe & Asia) ^{4.}

sacharavi

Fresh or brackish marshes; heliophilic

atroparvus

Fresh or brackish marshes, swamps and lagoons
Saltier situations favored; heliophilic

maculipennis

Still clear water, with abundant vegetation (if it does not produce shade)

pattoni

Stream beds in hills, rock pools, pockets near streams rich in algae; heliophilic

sinenses

Pools, ponds, swamps, shores of lakes, rice fields, slow streams; heliophilic

Mediterranean

labranchiae

Brackish coastal marshes. Freshwater in rice fields, upland streams, other situations

pharoensis

Swamps and rice fields with some vegetation

sergentii

Rice fields, borrow pits, irrigation channels, seppages, and drains

Australian

koliensis

Temporary pools in grassland and in pools along edge of jungle. Prefers water exposed to sunlight

punctulatus

Rain pools, stream margins, peridomestic water, bilge of small boats, hoofprints; heliophilic

faravti

Varies with locality, fresh or brackish, natural or artificial, clear or polluted waters

Footnotes:

- 1 Taken largely from Practical Malariology by Russell, West, Manwell and Macdonald. Oxford University Press, 1963.
- 2 Species are shown under a primary geographical region, but they may serve as vectors in adjacent areas as well (e.g. bellator in Central America and South America). For convenience they are listed once.
- 3 North America is no longer a malarious zone, except for areas of Mexico. However, the vectors are as abundant as they ever were and the area must be considered a receptive area for the disease.
- 4 Northern Europe and the U.S.S.R. are no longer malarious, but are receptive, as vectors persist.

Budget: Travel for two from the U.S. to Thailand,
expenses for one month

- \$4400.00

Vehicle for travel in-country

- \$ 750.00

Total: \$5150.00 for two years

Onchocerciasis - This disease, caused by filarial helminths transmitted to man by Simulium blackflies, is an important cause of human disease in much of tropical Africa, and parts of the Neotropical region. The Simulium have very narrow ecological requirements in their immature stages, and this fact prompted many of those who have examined the possibilities of remote sensing, such as Cline (13), to suggest that this might be an excellent system for further study. Briefly, all Simulium species require relatively clean rapidly moving water for survival of the immature stages.

The disease probably arose in Africa and was transported in negro slaves to the New World tropics. In Africa it has assumed a more serious proportion in recent years due to changes in the environment, particularly the initiation of large scale hydroelectric projects, some of which may have provided additional breeding places for the vectors. The known habits of the African and Central and South American vectors are summarized in Table 15 . It appears that the habitats occupied by the African species are much more diffuse, and that the zones of infection are correspondingly wide, as compared

to the relatively circumscribed foci in tropical America. In some large parts of West Africa onchocerciasis is a major cause of blindness.

The principal vector in that portion of Africa, Simulium damnosum breeds in any suitable oxygenated stretch of small rivers and streams. It appears to have a very wide latitude in its choice of aquatic habitats and a very long flight range, so it is quite difficult to control. Dripping of DDT into the major streams appears to work well, but reaching some of the smaller streams, such as those in the Volta River basin presents real difficulties. In East Africa the vector species, Simulium neavci passes its immature stages on the bodies of river crabs (Potomon sp.) which abound in rapids, near cataracts, etc. Garnham (14) has recently commented on the control of that species - "It was a simple enough procedure - dripping DDT emulsion into infested rivers and streams after measuring in 'cusecs' the rate of river flow. The difficulty lay in mapping these rivers, and McMahon in the course of his work in Kenya must have walked thousands of miles." One striking result of the insecticidal work in Kenya, Nigeria and along the Congo was the very long lasting abolition of the flies from the treated areas. In this case, proper planning and mapping of all of the potential breeding places, followed by treatment would seem to offer immense advantages, over say the insecticidal control of mosquitoes which must be repeated so often. In this case, remote sensing would seem to offer a real advantage, permitting the rapid mapping of the course of rivers and even small

tributaries by aerial photography. Where the rivers run under the shade of forest canopy it should be possible to do the mapping by radar. Detailed photo interpretation and access to reasonably good terrain maps should permit the pin-pointing of areas of radpis where the vectors tend to be most abundant - and should permit very accurate planning of control programs.

None of the project personnel have experience with the situation on the ground in Africa, but if work there were desirable as a test of remote sensing capabilities a number of universities and institutions in Europe and Africa should be available for cooperative projects.

However, the foci of onchocerciasis in Mexico, Central America and South America are much more convenient for study, and many of the techniques which could be developed there would be applicable in Africa. The disease in the Americas usually is restricted to much narrower and better defined geographical zones than in Africa. For instance, in Africa the disease occurs at altitudes from 900 to 3000 feet, a relatively vast area; while in Mexico and Guatemala it is confined to altitudes from 2000 to 4500 feet, and in much more discrete areas. Furthermore, the vectors in the Americas have been studied in very great detail, primarily by Dalmat (15) and a great deal of ecological information is available. In Guatemala where Dalmat worked, the vector flies are: Simulium metallicum, S. ochraceum and S. callidum, with the latter probably playing a lesser role. Dalmat (15) has identified the characteristic larval habitats for these species, as outlined in Table 15.

Table 15.

Characteristics of Breeding Sites of Simulium
vectors of onchocerciasis in Guatemala

Species	Habitat
<u>Simulium ochraceum</u>	infant and young streams under heavy canopy width - 1 in. to 1 ft. depth - 5 in. velocity - 1 to 10 in./sec. volume - 1 - 10 gal./sec. altitude - 3,000 to 5,000 ft.
<u>Simulium metallicum</u>	young, adolescent and mature streams under canopy or in open width - 1 to 8 ft. depth - less than 1 ft. velocity - 8 to 20 in./sec. volume - 1 - 10 gal./sec. to much higher altitude - 350 to 9,000 ft.
<u>Simulium callidum</u>	young, adolescent and mature streams largely in open or light tree cover width - 1 to 15 ft. depth - less than 1 ft. velocity - 1 - 30 in./sec. volume - not given altitude - 900 to 6,000 ft.

Dalmat initiated control studies, mixing DDT emulsion in the streams, and found, as reported by others in Africa, that one essential element in the program was the preparation of maps indicating the location of all breeding sites. With the very small rivulets involved in much of the breeding of S. ochraceum it is obvious that this is an extremely difficult problem. Furthermore, the effect of insecticidal treatment in Guatemala does not appear to persist over as long a period as in

Africa, requiring more frequent treatment.

The endemic onchocerciasis areas in Guatemala are limited to the Pacific slopes of the volcanoes of the Sierra Madre. Even the inhabited coffee plantation areas in this region are rugged (Figure 4), with many streams. Two project members (Hacker and Scanlon) visited the area for a short period, in the company of the medical officer charged with onchocerciasis control for Guatemala. The control program at present is devoted entirely to treatment of cases detected during routine visits to coffee plantations and village- - mostly by surgical excision of the nodules containing the adult worms, combined with some drug treatment.

A large number of streams in the endemic area near Yepocapa were examined and photographed. This is the same area studied by Dalmat and all of the stream types described by him were seen. One of the striking features was the heavy vegetation covering most of the smaller streams (Figure 5). Yepocapa is one of the easier villages to visit in the area due to some new road construction, but even here travel is very rugged by United States standards, and scheduled visits to all of the breeding sites would be difficult - impossible without adequate maps. We were informed that the budget of Guatemala would not presently support larval control measures. Actually, larvae were extremely scarce at the time, presumably due to a recent volcanic eruption which had deposited large amounts of dust and sand in the streams.

Surgical excision of the nodules is a temporary measure at best, and we were told that the same number of nodules were seen at each plantation visited each six months. We believe that larval control would be the best control method, particularly if the precise limits of distribution could be detected.

Recommendation - No specific program is recommended at this time. It is believed that contact should be made with public health authorities in Guatemala to determine if they would be interested in cooperating in a pilot study of the application of remote sensing to detection of breeding sites. It is possible that Mexican and Venezuelan authorities might also be interested. but the ecology of the disease is so well known in Guatemala that that would appear to be the best location for field work. However, in view of the present fiscal restraints and the lack of plans for larval control, it would appear that ground truth work would have to be supported almost entirely by NASA funds. Therefore, no specific recommendation is made for additional work at this time. This is unfortunate, since Cline (13) and a number of entomologists contacted during this study have indicated that this may be one of the best tests of remote sensing capabilities in communicable disease surveillance and control. Close liaison should be maintained with the Pan American Health Organization, particularly since plans have been made (but not implemented) for training several sanitary engineers or other health personnel in remote sensing under PAHO sponsorship.

Chagas Disease (American Trypanosomiasis) - This is an extremely important disease in tropical America, with millions of cases occurring in Brazil, Argentina, Colombia, Venezuela and other countries, with fewer cases through Central America to Mexico, and two cases known from Texas. The zoonotic form is found in many small and larger wild mammals, which are fed upon by the vector bugs (Hemiptera: Reduviidae) which live in or near the mammal dens and burrows.

The disease in man is transmitted almost entirely by triatome bugs (Triatoma infestans, Panstrongylus megistus, Reduvius personatus) which are domestic in habitat. There is a very strong correlation between housing type and the abundance of these bugs (Garnham, 1971), and they almost disappear in cement or concrete block housing with corrugated iron roofs. It would appear, therefore, that housing quality surveys in endemic areas might indicate rapidly the possible extent of infested premises, and that this might assist in planning attack campaigns - which are based on domiciliary spraying of persistent pesticides. However, it is unlikely that this application could stand alone, and it would more likely be a side-benefit of studies of urbanization discussed in another section of this report.

African trypanosomiasis - This complex disease is transmitted by a number of species of tsetse flies, higher Diptera of the genus Glossina. The species which serve as the vectors of the Gambian form of the disease (Glossina palpalis and G. tachinoides)

are largely riverine species. The females deposit single developed larvae, which then must burrow rapidly into friable soil to complete development into pupae and adults. French workers in Africa have worked out the ecologies of these two species in great detail. Transmission appears to be most intense during periods when the water courses are somewhat dry, tending to concentrate the flies and humans. Wild animal reservoirs may not be involved, or involved to only a minor extent. There does not appear to be any benefit to be gained from remote sensing at present - although a WHO/FAO expert committee report on the disease (16) notes that an attempt should be made to obtain quantitative estimates of the effect of many environmental factors that are known to influence transmission.

In East Africa the chief vectors are G. morsitans and G. swynnertoni. In contrast to the West African riverine species these are characteristic of the open savannah, interspersed with areas of forest gallery of scrub. The species utilize the open ground for hunting, and transmit nagana of game and domestic animals, as well as Rhodesian sleeping sickness to man. A great deal of work has been done on the ecology of the disease in East Africa, and it may be possible to construct maps of the potential distribution limits of the various tsetse species based on soil texture and moisture, distribution and type of vegetation sheltering the potential breeding sites, etc. One of the needs listed in the WHO/FAO publication cited above is: " - an urgent need for the periodic collection of data for the entire continent

by a central authority having access to the results of local survey and cartographical work." In West Africa the situation is so diffuse; there are large areas with heavy fly populations and no discernible human disease, that it seems worthwhile to look at the East African situation first. However, it must be recognized that work in Africa is difficult and expensive, and remote sensing equipment is not readily available.

Recommendation - The Public Health Ecology Section-MSD should open contact with workers in trypanosomiasis in East Africa, particularly the East African Trypanosomiasis Research Organization, Totoro, Uganda, to see if they have any interest in the type of assistance which remote sensing might offer.

Venezuelan equine encephalitis - This arthropod-borne virus has at least two ecological forms which should be considered separately - the enzootic and epizootic:

Enzootic - natural foci of VEE have been studied in Panama, several points in Central America and in the Everglades area of Florida. The latter appears to offer the most clear-cut example of the possible use of remote sensing and it will be described here in some detail. The situation in Panama appears to be quite similar, and it may be anticipated the Central American foci will also be similar, but involving other species of mosquitoes. The virus causing VEE exists in "silent" infections in small mammal populations in areas of the Florida everglades, apparently being transmitted from mammal to mammal by the

bite of Culex mosquitoes of the subgenus Melanoconion. These mosquitoes rarely bite man or horses, and relatively little has been known about their biologies. Recently, however, Sudia, et al. (17) have made detailed biological studies which indicate that the vectors are concentrated in hummock areas of the Everglades - slightly elevated mounds which have a characteristic vegetation differing markedly from the basic marsh vegetation. Initial examination by Sudia of color and color-infrared coverage of the Everglades area available in the MSC data bank showed great promise. The hummock vegetation may be detected without enhancement of the visual image, but may perhaps be even more readily detected by use of the multi-band camera system and the assignment of false colors to vegetation patches of specific types and density. Presumably, if the location of all of the sites for enzootic transmission could be plotted it might be possible to direct highly specific control programs against such sites. It is assumed that the epidemic form of the disease erupts from such foci when some still imperfectly known environmental conditions are precisely correct.

Epizootic and Epidemic - With the appearance of VEE virus in horses the number of mosquito species which can carry the disease to other horses and to man becomes very large.

The horses tend to circulate very high levels of virus which are capable of infecting almost any mosquito species. The problem of detecting mosquito breeding then becomes so general that it is doubtful that remote sensing can play a very large role. In addition, the response to the VEE episode in South Texas in the summer of 1971 was a rapid spraying with low-volume malathion insecticide over very large areas - and did not involve mapping of the breeding sites. It is likely that this pattern will be repeated whenever an epizootic occurs.

It has also been suggested that remote sensing might be used to detect large numbers of dead horses in areas along the advancing front of the epizootic, and thus aid in planning. This was attempted to a limited extent in the Corpus Christi outbreak in Texas in 1971, but the results were inconclusive. It has also been suggested that it might be possible to detect equines with higher than normal body temperatures by infrared scanning, and thus detect sick horses over large areas before dead horses are detected. This application appears to be technically feasible, but developmental work remains to be done.

Recommendation - It is recommended that MSC work as closely as possible with NCDC personnel in examination of the Everglades enzootic sites of VEE. If this technique can be developed there it is quite possible that many other arbovirus diseases will be

found to be amenable to the same technique. NCDC personnel apparently plan to continue ground truth operations in the Everglades. However, a recent communication from Sudia indicates that they will require the assistance of a photo-interpreter to proceed further with the program. It is suggested that Public Health Ecology make arrangements to supply the necessary photo-interpretation assistance from their own staff (when augmented), from other sections within MSC, or from contractor sources.

Eastern equine encephalitis - As with VEE, this disease exists in enzootic and epizootic (epidemic) forms. The enzootic foci with EEE are in freshwater swamps in the eastern United States. The vector, Culiseta melanura feeds on the birds which probably form the primary reservoir of the virus. At times the virus breaks out into the equine and human populations. Several enzootic sites have been identified on the east coast of the United States, and several organizations, including the Walter Reed Army Institute of Research and the office of the State Entomologist of Maryland are involved in attempting to define the breeding sites of C. melanura, and are cooperating with NASA agencies (Wallop's Island) in assessment of a possible role for remote sensing in this effort.

Recommendation - Since several Federal and State agencies are engaged in studies of the possibilities of remote sensing in this field no additional work is recommended.

Yellow fever and dengue - In the urban form in which these diseases pose the greatest threat for man, they share a vector, Aedes aegypti. This mosquito in its urban form utilizes artificial containers, tires, cemetery flower urns, etc. and it is possible that the urban remote sensing projects described in Section 6 of this report could furnish some data in this connection. However, the abundance of this species appears to vary over urban areas with little or no relation to the availability of breeding sites. This has been observed in such widely separated cities as Houston and Bangkok, as well as in San Juan, Puerto Rico (see Appendix A), so for the moment no further work is recommended on this subject.

The jungle form of yellow fever, at least in the Americas, is associated with massive deaths in troops of monkeys (as is Kyasanur Forest Disease in India, Table 13). Cline (13) and others have suggested that the movements of monkey troops might be followed by sensing their body heat. However, the precise relationship of monkey troops to the spread of the disease is a complicated problem. In Africa, death is more uncommon in the non-human primates. The mosquito hosts are often associated with peri-domestic plants such as the bananas. However, both banana plants and the Aedes species involved have a much wider distribution than the disease. All in all, yellow fever does not appear to be a fruitful area for further work at this time. However, this may merely reflect the relative lack of experience of the project personnel with this disease entity.

Other mosquito-borne diseases - Previous quarterly reports have summarized work conducted by Public Health Ecology Section personnel and our organization on the remote sensing of breeding sites of Culex quinquefasciatus, the vector of St. Louis encephalitis virus in many areas of the United States. These results also appear in NASA documents and will not be repeated here. This mosquito is also the vector of urban Bancroftian filariasis, a growing problem in the urbanizing areas of Africa and Asia. The basic problems in assessing the extent and production of this mosquito are the same as for many other species, that is, the determination of the physical, chemical and biological properties of the aquatic breeding sites which either favor or deter production of the immature stages. A proposal for studying this question in depth is outlined in the last portion of the Disease Control section.

Western equine encephalitis, Japanese B encephalitis, and the various members of the California encephalitis virus group are other agents for which a sufficient amount of ecological data may be available for application of remote sensing techniques for population surveillance and planning of control. WEE in particular has been studied in California and in West Texas in very great detail for a number of years, and for some areas of California workers at the University of California under Dr. W. Reeves have worked out epidemiological models in considerable detail. The vector, Culex tarsalis breeds in a wide variety of surface waters, but especially in sunny ground pools

and irrigated areas. Basically, however, the question with this and with all of the other mosquito-borne diseases in which the vectors utilize surface waters is - "are there characteristics in the breeding sites which can be detected by remote sensing, and which will give reliable data for predicting populations?" If there are, we may expect that the methods can be applied to a wide variety of mosquito-borne diseases.

Rocky Mountain Spotted Fever, and other Tick-borne Diseases -- Analysis of the possibilities of remote sensing capabilities with the tick-borne diseases has proven to be a particularly difficult problem. Some of the most definitive work on the ecology of diseases has been done with tick-borne agents, particularly at the Rocky Mountain Laboratory, U.S. Public Health Laboratory, and at various institutions in the Soviet Union. The latter work was summarized by Pavlovsky (18) who popularized the concept of "landscape epidemiology".

Rocky mountain spotted fever may be taken as an example of some of the tick-borne agents. It occurs widely in the United States and Canada, but within any geographical region may not be evenly distributed, but restricted to pockets, in which the agent may vary in virulence. Many small mammals are involved as natural enzootic hosts - and in the eastern United States the small rodent hosts may come right up to the limits of fairly large towns and cities. Workers in Virginia have recently attempted to identify the micro-habitat of the rodent-rickettsia complex with some success, but the situation over most of the range of the disease

is still incompletely understood. The tick-borne rickettsiae and viruses of the Soviet land mass have been keyed to certain large scale terrain and vegetation features (deciduous forest, tiaga, etc.) but Pavlovsky remarks: "The boundaries of a tick encephalitis nidus are diffuse, i.e. not sharply outlined; indeed, how can one determine accurately the outlines of a nidus based on ticks huddling together in the litter of a forest floor?"

For the moment it appears to us that the habits of the tick vectors and the small mammal hosts which are involved in all of these diseases are too imperfectly known to permit further analysis.

Recommendation - That further advice be sought from experts in the ecology of tick-borne diseases; particularly from the staff of the U.S. Public Health Service, Rocky Mountain Laboratory, Hamilton, Montana. They have had a number of sites of RMSF under surveillance for many years. One of the project staff (Scanlon) visited the Rocky Mountain Laboratory as a consultant for the National Institute of Health in September, 1971 and held preliminary discussions with some of the staff, but no firm recommendations were made at that time.

Scrub typhus - Up to a few years ago it would have appeared that this chigger mite rickettsial disease of the Orient was very suitable for delineation in nature by remote sensing. During World War II foci of the disease in Japan and SE Asia seemed to be related to certain open lands, particularly those overgrown

by elephant grass and similar grasses. Since that time, however, it has become apparent that the disease occurs in a wide variety of habitats including: volcanic sand on the slopes of Mt. Fuji, rocky soil on small islands off Honshu; margins of rice fields in Thailand, deciduous monsoon forest in Thailand; primary forest in Malaya; sand beaches in Malaya, etc. On the whole, the ecological picture has now grown so complex that no recommendations suggest themselves at present.

Arthropods with direct effects on man or livestock - The potentials for remote sensing were examined for several arthropods which are not vectors of human disease, but which either attack man causing injury or allergic reactions, or which cause mechanical injury. In many respects the mosquitoes could be considered in this light, for in the United States at least most control efforts are directed against mosquitoes, not in their role as disease vectors, but as pests - particularly in coastal areas. The other two species which are considered in this section are the fire-ant and the screw worm fly.

Fire-ants - The imported fire-ant (Solenopsis saevissima richteri) entered the United States some time around 1930, and has spread rapidly through many of the southeastern states. It has become very abundant in parts of the Houston area. The ants cause severe economic losses in some agricultural areas as the large mounds they construct of hard earth may damage mechanical equipment, and they are alleged to devour the young of quail and other ground dwelling

birds. It is certain however, that they can cause intense pain when biting and stinging humans who disturb their mounds. Dermatologists at Baylor College of Medicine have encountered a number of very serious cases in the Houston area, and area physicians in general have reported a number of serious to dangerous cases. In 1957 over 300 persons were treated for ant stings at Ft. Benning, Georgia, and similar incidents have been reported from other areas.

Early attempts to control the ants over large areas by means of chlorinated hydrocarbon insecticides led to widespread controversy over death of non-target organisms.

At present, the U.S. Department of Agriculture is cooperating with state agencies for a much more tightly controlled application of Mirex, a more specific pesticide. Texas Department of Agriculture officials are cooperating in the program. One of the first procedures which will have to be taken is the delineation of the precise distribution of the ants, and the mapping of the infested area in order to plan the insecticide distribution program.

NASA has already cooperated with the USDA in a flight over infested areas which clearly indicated that the fire-ant mounds could be detected in color and color-infrared photography, at least in open ground. While it is doubtful that mounds can be detected readily under tree cover, it appears that the majority of the mounds are constructed in relatively open areas. At least it should be possible to determine the limits of distribution in

any area by finding those mounds which are accessible.

Recommendation - Since NASA-MSD has already begun cooperation with USDA in detection of fire-ant mounds, with promising results, it is suggested that cooperation be initiated with Texas State Agricultural Department personnel who will be doing the ground truth work at any rate. With the State of Texas personnel and Public Health Ecology Section personnel cooperating there should be no need for additional expense for ground truth operations.

Screw worm - The primary screw worm (Cochliomyia hominivorax) only rarely infests man in its larval stage, often with disastrous results, but is of interest primarily as a serious pest of livestock. This results in economic loss, and in the loss of useful protein. In recent years striking successes have been attained in eliminating screw worm from the United States by means of application of the sterile male technique. At present, the species is found in various places in Mexico and tropical America, and a cordon sanitaire is being maintained across northern Mexico, by the continued release of sterile male flies.

The female fly deposits its eggs in any break in the skin of the host, and the larvae, often hundreds to thousands, burrow through the flesh for several days until they reach the prepupal stage. At that time they leave the host, burrow into the ground and undergo a pupal stage of some seven days. It is only at the prepupal stage that remote sensing might play a part. A check of the literature on the biology of the screw worm reveals that relatively little is known concerning the type of soil required for these stages, the

effects of local vegetation, etc. Some data are available on soil temperature, but these need to be brought up to date and integrated in a comprehensive model to explain the survival of the flies in overwintering pockets in northern Mexico, and their extension into additional areas as the season progresses. The accumulation of such data, combined with a determination of whether the critical limiting factors can be detected by remote sensing should make it possible to plan supplementary control measures and perhaps to assist in planning releases of sterile flies.

The U.S. Department of Agriculture is cooperating with interested authorities in Mexico in maintenance of the barrier, and are planning to conduct studies of seasonal extension. The Mexican authorities have also expressed interest in various aspects of remote sensing, and have trained personnel in various aspects of the subject. However, what appears to be needed is an entomologist experienced in population dynamics and insect ecology to follow the rise and fall in population, the dispersal and ecology of the flies. The most appropriate place to conduct this research at present is in Mexico, although the fly extends much further south in the tropics. Such studies cannot be conducted in the continental U.S. at present, although an infestation still exists in Puerto Rico.

Recommendation - That Public Health Ecology group - MSC cooperate with USDA and Mexican authorities in the present studies of the ecology of screw worms in Mexico, with the aim of determining whether remote sensing can be of assistance in plotting the distribution of

the species and its periodic extension of its range. Much of this extension may be due to movements of infected animals, but seasonal and ecological factors affecting the prepupae and pupae are also believed to be involved.

Mosquitoes - In the course of analyzing the potential role of remote sensing in the surveillance and control of the various arthropod-borne diseases during this contract it became apparent that one of the most promising uses of the technique in the field of public health would be the study of mosquito breeding sites. Not only are mosquitoes the most important vector arthropods, for a wide variety of extremely important human and animal diseases - they are also important as pests. Many coastal areas of the United States, for instance, would be almost uninhabitable were it not for routine mosquito control activities. Far more tax money is spent in the U.S. annually on control of pest mosquitoes than on the control of vector species. Much of this large sum of money is expended for repetitive chemical control procedures, applied with ground equipment, or by aerial spraying. With the rising tide of protest over the large-scale release of pesticides in the environment it has become extremely important to make sure that control activities are directed to the target species with the greatest precision possible, and with as few side effects on non-target organisms as possible. This requires that our understanding of the ecologies and rates of production of the various

mosquito species be greatly improved.

In the era when mosquito control depended on massive changes in the environment by drainage, without respect to its effect on useful organisms; or in the use of non-specific and often persistent pesticides the requirements for detailed knowledge of species ecology was all too often overlooked. In the last few years it has become evident that an integrated control program - utilizing a wide variety of control techniques in a flexible pattern is needed. And for this we need to know far more about the environmental factors, physical and biological, which determine the size of mosquito populations than we have had available in the past. Fortunately, many of the tools needed for such understanding have now been developed to a high degree, including computer techniques which permit the analysis and integration of a large number of physical, chemical and biological measurements into mathematical statements of population changes.

The use of remote sensing depends upon the detection and understanding of various "signatures" which can be used to plot and keep under surveillance the breeding sites of the mosquito species under study. During the contract, but in a separate study, project personnel of the School of Public Health cooperated with Public Health Ecology personnel and members of the Harris County Mosquito Control district in a limited attempt to define the breeding places of Culex quinquefasciatus, the urban vector of St. Louis encephalitis virus in the Houston area. This included limited chemical and bacteriological studies of water from breeding and non-breeding sites, and a single

flight. This work was discussed briefly in previous quarterly reports, and will be reported more fully elsewhere. The preliminary work clearly showed the need for much additional ground truth study before analysis of remotely sensed data could begin in any meaningful way. In the meantime, the Public Health Ecology group has also cooperated in preliminary studies of salt and fresh-marsh pest mosquitoes with personnel of the Division of Mosquito Control, New Orleans Parish, under Dr. G.T. Carmichael. The mosquitoes utilizing the coastal marsh habitat are extremely important, and there appears to be a very strong possibility that the immature mosquito stages are distributed on the marshes in such a way that their areas of abundance may be detected from vegetational associations. Very slight changes in marsh elevation, salinity and other factors are known to cause marked shifts in vegetation, which may be detectable by remote sensing techniques once the proper signatures are identified. Here too, however, more work is needed on the precise chemical and biological controls which affect mosquito distribution.

Aside from the treehole and container breeding species of mosquitoes, and those with very special habitats (such as Anopheles bellator) it would appear that techniques developed for the detection of larval habitats of one species may give leads for other species. It would therefore appear that an intensive study of a few species in an accessible area should be undertaken as soon as possible, to determine as rapidly as possible which environmental determinants of species abundance and distribution may be expected to be amenable

to remote sensing.

Recommendation - That Public Health Ecology group, with as much outside cooperation as necessary, determine the precise chemical, physical and biological factors in the environment which promote the populations of selected mosquito species, including the influence of meteorological changes, plant associations, etc. That the mosquito species chosen include representatives of at least the following groups: 1) species such as Culex quinquefasciatus, Anopheles stephensi and Culex tarsalis which are important disease vectors, and which appear to thrive in water of high organic content, including sewage pollution; woodland and open standing water species, such as many Aedes and Psorophora which are both disease vectors (Californian encephalitis virus, Venezuelan equine encephalitis virus) and severe pests; marshland species, such as Aedes taeniorhynchus, A. sollicitans and some Psorophora species which make some areas almost uninhabitable, which cause severe losses as livestock pests; and which may also play a role as vectors of VEE and other viruses under some conditions.

Such studies should employ sophisticated analytical, ecological and statistical techniques in the assembling of ground truth data to prepare an integrated picture of all environmental determinants of mosquito populations - supplemented in the later stages by planned remote sensing flights.

Possible budget (including procurement of laboratory and field equipment for the first year, not repeated)

Equipment - Laboratory - \$15,000.00
Field (primarily micro-meteorological - \$8,000.00
w/automatic data recording)

Personnel	-	Investigators	-	\$32,000.00
		Technicians	-	\$30,000.00
Supplies			-	\$ 8,000.00
Travel			-	\$ 2,500.00

TOTAL: \$95,500.00

6. URBAN HEALTH/DISASTER ANALYSIS

Remote sensing of urban areas is capable of providing a wealth of information to interested and capable users. Frequently, however, its potential is not realized by researchers who continue to use more familiar methods. On the other hand, unsophisticated users need to be cautioned about problems and given some guidelines in imagery uses. But unless the value of remote sensing is recognized and demonstrated, applications will lag behind its quality and quantity.

Urban land use area in the United States makes up a very small proportion of overall area - hardly more than one percent. In terms of population, however, cities house over three-quarters of the total. In terms of productivity, they far exceed similar sized rural land. In terms of problems, they also over-shadow other areas with the concentration of population emphasizing those problems. For example, natural disasters such as the Corpus Christi hurricane can cause damage to a great many more people and structures than in a sparsely populated area. As a result, cities are important far out of proportion to their areal extent.

As urban areas continue to grow, ecologists and others are becoming more concerned about cities and the quality of their environment. New towns are being planned, urban renewal is replacing central

city slums, and peripheral expansion is occurring around every large city. These new urban environments are large in extent from neighborhood to community size where action could enhance the public well-being. But even where the mechanisms to put plans into action exist, we are far from knowing the path to the optimal conditions for which we are striving. Thus, research into the present urban environmental situation, its causes, effects, and relationships is necessary in order to improve upon it and the resultant health of the public.

The urgency to improve urban conditions for the present and future populations demands rapid data acquisition. Frequent changes are made in cities - construction takes place, activities replace others and movements among them shift. Therefore, frequent updating of information is needed. These two requirements can be met by remote sensing sources. Experienced photo interpreters can tabulate reliable data quickly, and anyone desiring a reconstruction of past urban circumstances knows that aerial photos are his best source for many kinds of information otherwise unavailable.

Cities can be treated in two ways - as points and as areas. Relationships between cities as points and health can only be broad. Point characteristics include size, shape, overall density and function of each city, as well as its relation to other cities in terms of distance and arrangement. Small scale imagery can reveal the areal sizes and shapes of cities by color and pattern differences. The major function is often determined by the locational patterns of cities as a network. Site characteristics on a broad level can also be

determined. Such geographical properties visible on aerial photographs along with supplementary data may have significant relationships with health characteristics. Cities within specific size classes and having a functions such as heavy industry may exhibit high incidences of respiratory ailments or other health outcomes. Port cities or those with special locational features may reveal peculiar health problems.

Studies of the subregions and subpopulations within cities must treat cities as areas. Larger scaled imagery is required in order to look at a point as an area. Urban applications of remote sensing have thus far primarily dealt with this scale.

Previous Studies

1. U.S. Geological Survey, Technical Letter, NASA-138. Side-looking Radar in Urban Research: A Case Study. Eric G. Moore, Northeastern University, Department of Geography, Evanston, Illinois. October 1968. Contract No. R-09-020-024. STAR N69-16108. REDAF No. NR-D5-00-000-00138.

Moore discusses transportational features that can be reliably identified such as railroads, roads, wharves and waterways but points out that parking lots cannot be distinguished.

The gross industrial pattern can be identified but commercial strip and industrial strip are difficult to distinguish.

Image texture provides the basis for classifying land uses although the boundaries are not distinct.

2. U.S. Geological Survey, Technical Letter NASA-135.

Thermal Infrared Imagery in Urban Studies. Barry S. Wellar, Northeastern University, Department of Geography, Evanston, Illinois, December 1968. Contract No. R-09-020-024. STAR N69-14344. REDAF No. NA-D5-00-000-00135.

Thermal Infrared imagery is capable of making positive identification of all the transportation features that Moore found by side-looking radar plus large parking lots and automobiles with running motors.

Commercial districts and strip development are identifiable. Problems are multi-story apartment houses and industrial land use similarities. Industry often has terminal facilities and larger buildings. The CBD is distinguished by such features as size and locational grouping of structures, parking lots, and street widths.

Hospitals may be identified on the basis of size and schools by adjoining athletic fields.

House counts were made but some were obliterated by tree coverage. Sizes of single-family units are not determinable nor are yard spaces between houses. Apartment houses and commercial structures could not be distinguished. Golf courses, parks, cemeteries and other recreational areas were identified.

3. U.S. Geological Survey, Technical Letter NASA-118. Remote Sensor Imagery in Urban Research - Some Potentialities and Problems. Eric G. Moore and Barry S. Wellar, Northwestern University, Evanston, Illinois. May, 1968. Contract No. 14-08-0001-10654. STAR N68-25554. REDAF No. NR-D5-EJ-998-00118.

The authors discuss potential uses especially in traffic-flow and land-use investigations.

4. Urban and Transportation Information Systems. Annual Report, April 1966. Northwestern University, Research Office, Department of Geography, Evanston, Illinois. Contract No. NONR 1228 (37), Task NR 389-143. STAR X69-74535. REDAF No. NR-D6-EJ-029-00018.

A controlled experiment with a vehicle convoy was to have been run, but uncertain flight scheduling canceled it.

5. U.S. Geological Survey, Technical Letter NASA-153. Analysis of Urban Residential Environments Using Color Infrared Aerial-Photography - An Examination of Socioeconomic Variables and Physical Characteristics of Selected Areas in the Los Angeles Basin. Robert H. Mullens, University of California, Department of Geography, Los Angeles, California (Addendum) An Application of the Concepts of the Los Angeles Residential Environment Study to the Ontario-Upland Region of California. Leslie W. Senger, University of California, Department of Geography, Los Angeles, California. May 1969.

Contract No. W-12570. REDAF No. NR-D5-EJ-130-00153.

Color infrared aerial photographs allow identification of land uses, lot and home size, vegetation quality, litter and street condition. The latter three depend on the judgment of the researcher to a great extent.

6. U.S. Geological Survey, Technical Letter NASA-120. Utilization of Multiband Aerial Photographs in Urban Housing Quality Studies. Barry S. Wellar, Northwestern University, Department of Geography, Evanston, Illinois. Contract No. 14-08-0001-10654. STAR N68-25422. REDAF No. NR-D5-GJ-043-00120.

This study contains a table of characteristics of

- 1) land crowding;
- 2) condition of Private Free Space;
- 3) Nonresidential land uses;
- 4) Hazards and Nuisances from Natural Phenomena;
- 6) Inadequate Utilities and Sanitation;
- and 7) Inadequate Basic Community Facilities, most of which are discernible from imagery.

7. U.S. Geological Survey, Technical Letter NASA-119. Generation of Housing Quality Data from Multiband Aerial Photographs. Barry S. Wellar, Department of Geography, Evanston, Illinois. Contract No. 14-08-0001-10654. STAR N68-25878. REDAF No. NR-D5-GJ-043-00119.

Multiband aerial photography allows identification of motor vehicle facilities in terms of size, direction and amount of flow, and parking lots.

Suggested Applications of Remote Sensing in Urban Health

Validation of simple identifications is the first step toward regular application of remote sensing. Using visual surrogates for other types of data is a more sophisticated application also needing verification. Suggestions for monitoring and analyzing urban data related to health follow (Table 16). A specific program of study of urban ecology in relation to remote sensing in the Houston area is under development at present by the Public Health Ecology Section-MSc, so no specific outline or budget are presented here.

As noted in the introduction to this section, the field of disaster analysis may be regarded as a special topic under urban studies, since the public health effects of such natural disasters as hurricanes, tornadoes, volcanic eruptions, etc. are directly and strongly related in their impact to the density of the human populations in the affected areas. Preliminary examination of the material in the NASA data bank from the Lubbock tornado, Hurricane Camille and similar phenomena clearly indicate that remote sensing may aid immeasurably in rapid assessment of the effect of the disaster, and in planning for provision of water, sewage and other public health related essentials in the immediate post-disaster period.

By the very nature of this activity it is impossible to propose specific work plans, and one must work with targets-of-opportunity. There probably is no external agency which can approach the capabilities of NASA-MSc personnel in analysis of photographic data from disaster areas. It might be profitable for NASA to make contact with the

Smithsonian Institution Project for the Investigation of Short-lived Phenomena (volcanic eruptions, earthquakes, etc.) which maintains surveillance (including aerial photography in some cases) over many events which may be of interest in assessing the role of remote sensing in disaster analysis.

Table 16

Urban Phenomena Which May be Studied by Remote Sensing Techniques, With an Indication of the Specific Signatures to be Examined

Phenomena	Health Relationship	Signature
1. Urban Land Use	Rural-urban differences in health, sprawl and health effects, city to city differences.	
2. Residential Land Use	To identify dwelling distribution and night-time population distribution.	Bulk or urban land structure size.
Residence Type	To identify multi-family vs. single family and determine population counts and distribution.	Size and height of bldg. Parking spaces.
Residence Quality	To identify neighborhood quality and indicate areas of present and potential problems (crime, disease).	Size of bldg., bldg. density, curbing, litter, street condition, lot coverage, yard size and condition, bldg. frontage, multi-vs. single-unit structures, proportion of other uses, distribution of other uses (conflicts in land use).
3. Industrial and Commercial	To identify employment centers, traffic generators, daytime population distribution (e.g. for bomb shelter planning), land use conflicts (noise and pollution of residences).	Bldg. size and shape, parking lots, unloading space.

Phenomena	Health Relationship	Signature
Obnoxious Industry	To identify pollution sources, industrial health problem areas (accidents and ailments).	Smoke plumes, rail spurs, storage lots, loading areas, structure size and shape, source area of identifiable water pollution.
Commercial Quality	To identify neighborhood character and indicate areas of present and potential problems (crime, disease).	Landscaping, offstreet parking, lack of pickups and trucks in parking lots.
4. Public Services	To identify service areas, non-taxable land use.	Presence of athletic fields and other features characteristic of each service.
Schools	To assess equity of distribution to all people.	Athletic fields, schoolyard play equipment.
Hospitals	To assess equity of distribution to all people.	Structure size and height, evidence of power plant.
Parks	To assess equity of distribution to all people.	Recreational equipment.
5. Transportation	To identify movement paths and capacity.	Linear pattern, presence of carriers.
Freeways and interchanges, streets, alleys	To identify congestion spots, hazardous areas, best access locations for emergency services, clutter and hazard of advertising signs.	Linear pattern, size, heat generators, number of cars per unit length, traffic density.

Phenomena	Health Relationship	Signature
Railroads and Switch-yards	To identify noise sources, possible location of undesirable transients, potential accident areas.	Pattern, railroad cards, roundhouses.
Airports	Noise and air pollution source, nucleus of future growth, land traffic generator.	Runways, hangars, parked aircraft.
Sidewalks and street lights	Provision for pedestrians to increase safety. To identify high potential crime areas on dark streets.	Street lights, "hot spots".
Carriers in movement	To make origin-destination studies	"Hot spots".
6. Vacant land	Rodent infestation areas, hazardous garbage, etc., to children.	Litter, vegetation quality.
7. Natural phenomena		
Cloud cover and radiation	To relate sun deficiency to health (skin cancer, etc.), mental health (depression).	
Topography	Flood potential, air pollution pockets.	
Tree cover	Aesthetic value.	
8. Spatial form of land uses	Concentration vs. dispersion is a factor in degree of problems and planning services.	Outline areas instead of individual occurrences.
9. Dynamics of land uses	Indicates changing structure of urban areas.	Compare photos of different times, any desired interval

7. RADIOLOGICAL MONITORING

A periodically recurring problem with public health implications is the loss of radioactive sources or accidental dispersal to the environment of radioactive materials. These incidents can occur in connection with transportation of radioactive materials or as releases from established sites. Rapid recovery of lost sources or rapid delineation of a contaminated area is important from the public health standpoint.

An example of a lost source event occurred in June, 1968. A shipper reported that a 0.325 Ci Cobalt-60 source had been lost from his truck somewhere between Salt Lake City, Utah and Kansas City, Missouri, a distance of approximately 1100 road miles. A similar 5 Ci Cobalt-60 source was responsible for the death of four members of a Mexican family in 1962. Another incident occurred July of 1970 when an Athena Rocket operated abnormally and crashed in Mexico with two 0.40 Ci Cobalt-57 sources aboard. An example of widespread environment contamination occurred at Windscale, England in 1957. As a result of a reactor fire, thousands of Curies of mixed fission products, mostly iodine 131 escaped into the environment and contaminated thousands of acres of farmland. Contaminated dairy products resulted in doses on the order of 10 rads to the thyroids of hundreds of individuals.

The safety regulations governing the nuclear industry and shipment of nuclear products are probably as strict or stricter than those governing any other class of potentially hazardous materials. It seems unlikely that the regulations will become more stringent and so it is reasonable to estimate that incidents involving radioactive materials will increase roughly in proportion to the increase in use of these materials. Nuclear power plants, fuel reprocessing plants and industrial uses of isotopes are all increasing in number.

Remote sensing with air-borne radiation detectors has been used in connection with lost sources and environmental contamination. The Aerial Radiological Measuring System aircraft (ARMS) was used to locate the 0.325 Ci Cobalt-60 source lost in transit and in locating the two .400 Ci sources in the Athena instrument package. Ordinary portable scintillation equipment has been tested in a helicopter for potential use in radiological emergencies. It would seem that remote sensing of gamma radiation has great potential for rapidly locating lost sources and delineating contamination areas.

Most of the existing remote gamma-sensing equipment is used for mineral exploration studies and for geologic research. At the present time there is probably insufficient economic justification for remote gamma sensors to be used exclusively for radiological emergencies but it should be possible to make arrangements for occasional use of existing devices for research, training, and emergencies.

The application of remote sensing to radiological emergencies has limitations. It is not possible to image with gamma radiation, and absorption of the radiation in air coupled with the cosmic ray

background renders the method useless at altitudes over 1000 feet. Therefore, the platforms for remote sensing of gamma radiation are limited to low flying aircraft and helicopters. Another limitation is inherent in the radionuclides themselves; not all hazardous radioactive materials have sufficient gamma radiation to be detected by remote sensing methods. Furthermore, a source lost in transit is not amenable to remote sensing if its shield remains intact. Fortunately, a source with an intact shield is not as much of a public health hazard as an unshielded source.

A program to evaluate the usefulness of remote sensing in radiological emergencies might take the following form:

1. Define a geographical area of interest.
2. Arrange for use of remote sensing instrumentation and aircraft with an existing user of such equipment.
3. Theoretically evaluate the effects of the several limiting parameters (altitude, ground speed, X-ray energy, source geometry, etc.) upon the sensitivity of the detection equipment.
4. Test under actual flight conditions, the results of the calculations indicated above (item 3).
5. Evaluate as a function of space and time the background radiation in the geographical area of interest.
6. Determine, taking into account the detection sensitivity, and the background, the limits of source strengths and configurations that can be detected.

7. Examine reports of previous radiological incidents to see if remote gamma sensing would have been of value.

When the research is concluded, a demonstration could be established.

1. Train several persons in the use of the equipment for radiological emergencies; establish an alert scheme.
2. Publicize the availability of the equipment to appropriate persons in the geographical area of interest.
3. Perform remote surveys upon request of authorities.

References

Shapley, D. 1971. Radioactive Cargoes: Record Good But Problems Will Multiply. Science 172, pp. 1318-132

Morgan, K.Z., and J.E. Turner. 1967. Principles of Radiation Protection. Wiley, New York, p. 43.

Morgan, K.Z. and J.E. Turner, Ibid. p.54.

Weissman, V.G. and J.E. Hand, 1968. ARMS Recovery of Lost Cobalt-60 Source, EGG - 1183-1395, Technical Report No. L-901.

Deal, L.J., J.R. Doyle, Z.G. Burson and P.K. Boyns. 1971. Locating the Lost Athena Rocket in Mexico by the Aerial Radiological Measuring System (ARMS). Submitted for publication to Health Physics.

Lister, B.A.J. 1963. The Use of Helicopters for Emergency District Survey After an Accidental Release of Radioactive Material, Health Physics, 9. pp. 309-314.

Appendix A - Puerto Rico

During November, 1971 two members of the project (Hacker and Scanlon) visited Puerto Rico for assessment of several field studies which might be amenable to application of remote sensing techniques. In San Juan primary attention was devoted to schistosomiasis investigations being conducted by the Tropical Disease Section, National Communicable Disease Center. These are covered in the body of the report in detail. Primary personnel contacted at TDS were: Dr. Barnett Cline (Director) and Dr. Dwayne Lee, Parasitologist. Dr. Cline indicated that the facilities of TDS would be available for any joint field studies of the application of remote sensing which might be arrived at with SPH or NASA-MSD workers.

Conversations were also held with Dr. Lawrence Ritchie, Acting Director of the Medical Section of the U.S. Atomic Energy Commission facility in San Juan. Dr. Ritchie confirmed the preliminary estimates of the TDS workers on the association of the snail hosts of schistosomiasis with certain types of emergent vegetation. He also suggested that remote sensing might have some application in the studies on the epidemiology of Fasciola hepatica in domestic stock which he is conducting in the wetlands on the northeastern coast of Puerto Rico. This disease is of some importance in man in various parts of the world, including Cuba, but its greatest importance lies in the loss of protein

involved in infections of the liver and other organs of domesticated animals. Its transmission depends on the ingestion of metacercariae encysted on aquatic or wetland vegetation. The cercariae are released from certain species of snails which inhabit such biotypes. Dr. Ritchie's studies in Puerto Rico were not believed to be at a point of development where remote sensing techniques could be used at present, but he should be contacted in connection with any planned missions over Puerto Rico to see whether or not his study areas might be included. Ground truth data in this case would be the determination of specific plant community associations with the areas of greatest danger of transmission of the parasite to livestock. This problem is very similar to the question of plant associations with salt marsh mosquito breeding, and it seems highly likely that such associations can be developed. Dr. Ritchie is one of the most highly qualified workers in the world in the epidemiology of helminth infections.

Doctors Hacker and Scanlon, accompanied by Doctors Cline and Lee of the TDS also visited the Pioneering Entomology Laboratories (PEL) of the University of Puerto Rico, at Mayaguez. Personnel contacted there included Dr. Chester Moore and Dr. Maldonado-Capriles. Discussions were held on the possible application of remote sensing techniques to studies of the epidemiology of dengue. This topic was also discussed in the body of the report. The studies in Puerto Rico are highly significant because of the apparent increase in dengue in the Caribbean in recent years,

the appearance of at least two dengue serotypes in the area, and the possibility that the dengue shock syndrome (dengue hemorrhagic fever) may appear there. It was concluded from the examination of available data, the rapid urbanization of Puerto Rico, and the almost ubiquitous availability of breeding sites for A. aegypti on the island that remote sensing probably offered little advance over present methods. One interesting finding by Dr. Moore and his associates is the presence of aegypti in the many limestone sinks in the northwestern portion of the island. The use of such habitats might indicate that the species is becoming feral in Puerto Rico, but the presence of humans near the habitats and the rapid spread of inhabited areas in this portion of the island probably makes this a moot point at present.

Appendix B - Central America

During November two members of the project (Hacker and Scanlon) visited several countries in Central America in connection with contract activities. Several elements examined during this period are covered in the body of the report. The following is a summary of the entire period.

In El Salvador both participated in an international symposium on malaria and malaria eradication, sponsored by the National Communicable Disease Center, Atlanta, and the Pan American Health Organization. Discussions on the possible application of remote sensing to malaria studies and control operations were held with: Dr. T. Lepes, Director, Division of Malaria Eradication, World Health Organization, Geneva; Dr. L.J. Bruce-Chwatt, Director, Ross Institute, London; Dr. D. Sencer, Director, NCDC, Atlanta; Dr. D. Kaiser, Chief, Malaria Eradication, NCDC, Atlanta, and many other workers from countries in the Central America region. The topic of remote sensing was not formally on the agenda of the meeting, but a large number of workers indicated an interest in the techniques.

In Panama Doctors Hacker and Scanlon discussed remote sensing with Dr. Karl Johnson and members of his staff at the Middle America Research Unit (MARU) in the Panama Canal Zone. The specific questions examined were the possible applications of the serological data bank of MARU to epidemiological studies and coordination with environmental discriminants of disease distribution. The conclusions reached are given in the body of the report. A field trip was also

made with Major L. Rutledge of the MARU staff to see breeding sites of sandfly species (Phlebotomus) which are the vectors of mucocutaneous leishmaniasis (Leishmania braziliense) in Central and South America. Many of the sandfly species appear to have their larval habitats tied closely to certain tree species - inhabiting the forest litter at their bases, or debris collecting in forks, etc. However, the sandfly fauna is quite complex, the precise species involved in the transmission of the disease in jungle areas is not known, and the investigations of the larval habitats have only recently been started. Therefore, it is too early to determine whether or not the biological associations will be close enough to permit mapping of dangerous areas by remote sensing.

In Guatemala Doctors Hacker and Scanlon were interested primarily in visiting the larval habitats of Simulium species which are the vectors of onchocerciasis. Habits on the Pacific slope of the volcanoes near Guatemala City were visited in company with Dr. L. Figueroa of the Onchocerciasis Control Section, Ministry of Public Health of Guatemala. The onchocerciasis control program in Guatemala at present consists entirely of case finding in the coffee plantations and other inhabited areas of the endemic zone, and excision of the nodules produced by the worms. Although insecticidal treatment of the larval habitats was used some years ago with considerable success, it has been abandoned, presumably primarily for economic reasons. Although, as noted in the body of the report, it appears that remote sensing of the larval habitats might be quite feasible, it appears

unlikely at present that this would be used to plan control programs based on larvicidal treatments.

In Guatemala City conversations were also held with Dr. L. Mata, Institute of Nutrition for Central America and Panama (INCAP), who has cooperated with Dr. Johnson and his associates at MARU in the application of serology to plotting of the distribution of various diseases in Central America. This activity is discussed under epidemiology of communicable disease in the body of the report. The INCAP serological data, according to Dr. Mata, has been processed from punched cards to tape and discs for computer processing, and thus may be available for remote sensing applications in a readily retrievable form. The INCAP serological data pertain primarily to bacterial diseases, with most of the virus serology (primarily arbovirus) still being held by MARU. Serological specimens have been split by the two organizations and the serum banks are held in duplicate for further work. It appears that these serological data can be plotted by geographical location, and that these may in turn be keyed for terrain, soil type, vegetation type, etc. However, an immense amount of work remains to be done, and the environmental data are not presently in the system. One might choose a particularly promising disease and set up a system for cataloguing the areas of high prevalence of selected environmental factors - then plan to examine these by remote sensing techniques. However, none of this is being done at present. Attachment of personnel to INCAP for this purpose might be a promising lead. INCAP is sponsored in part by the Pan American Health Organization, and that organization

has expressed an interest in training one or two persons in remote sensing techniques.

Appendix C - Personnel Involved in the Project

The following personnel of the School of Public Health, University of Texas have been involved to varying degrees in the remote sensing project; either in primary analysis of the data available, accumulation of literature and other supportive activities; or in the preparation of segments of the various reports. Those whose names are followed by an asterisk have been supported by funds provided by the contract. The services of all other individuals have been provided by the School of Public Health.

Administration and support:

Dr. John E. Scanlon - Project Manager

Mrs. Elaine Akey - Secretary

Mrs. Genevieve Lopez - Secretary*

Miss Kay Littrell - Data Retrieval Specialist*

Air Pollution:

Dr. Richard Severs

Dr. Leslie Chambers

Water Pollution:

Dr. Ernst Davis

Dr. Stanley Pier

Urban Development/Disaster Analysis:

Dr. Marjorie Rush

Dr. Arthur Atkisson

Mr. Ron Baba

Disease/Vectors:

Dr. John E. Scanlon

Dr. Carl Hacker

Dr. Barnett Cline (Consultant)

Mr. Freddie Miller, M.S.*

Mr. Matthew Yates, B.S.*

Radiation Health:

Dr. Thomas F. Gessell

Appendix D - Equipment Purchased With Contract Funds

Microfilm Reader/Printer, 3M	-	\$1,646.25
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Norelco, Transcriber for Mini-Cassettes		
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	-	\$ 90.00
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8. REFERENCES

1. National Aeronautics and Space Administration Manned Spacecraft Center, 1970. Earth Resources Program, Synopsis of Activity.
2. Johnson, Philip L., ed. Remote sensing in ecology. 1969. University of Georgia Press.
3. National Research Council. 1971. Committee on Remote Sensing for Agricultural Purposes, Remote sensing; with special reference to agriculture and forestry. 424 pp.
4. NASA-MSC. 1970. Earth Resources Remote Sensing Systems.
5. Anderson, R.R. "Spectral Reflectance Characteristics and Automated Data Reduction Techniques Which Identify Wetland and Water Quality Conditions in the Chesapeake Bay", Third Annual Earth Resources Program Review Vol. III, MSC 03742.
6. Polcyn, F.C. "Measurement of Water Depth by Multi-spectral Ratio Techniques", Third Annual Earth Resources Program Review, Vol. III, MSC 03742.
7. White, P.G. "Visible Region Remote Spectroscopy of Polluted Water", Third Annual Earth Resources Program Review Vol. III, MSC 03742.
8. James, W.P. 1970. Doctoral Dissertation "Air Photo Analysis of Waste Dispersion from Ocean Outfalls", Oregon State University, Department of Civil Engineering.
9. Van Ness, G.B. 1971. Ecology of Anthrax. Science 172: 1303-1306.
10. Jordan, P. and Webbe. 1969. Human Schistosomiasis. Thomas 212 pp.
11. Wright, J. 1972. Annual Review of Entomology, Vol. 17. Academic Press.
12. Scanlon, J.E. and Sandhinand, U. 1965. The distribution and biology of Anopheles balabacensis in Thailand. J. Med. Ent. 2: 61-69.
13. Cline, B. 1970. New eyes for epidemiologists: aerial photography and the remote sensing techniques. 92: 85-89.
14. Garnham, P.C.C. 1971. Progress in Parasitology. Athlone Press. 224 pp.

15. Dalmat, H. 1955. The Black Flies (Diptera, Simuliidae) of Guatemala and Their Role as Vectors of Onchocerciasis.
16. WHO/FAO. 1969. African trypanosomiasis. WHO Technical Series No. 434. 79 pp.
17. Sudia, D.J. 1972. Personal communication.
18. Pavlovsky, E.N. 1966. Natural Nidality of Transmissible Disease. Ed. Levine. University of Illinois Press.

Figure 1.

Topographic map of schistosomiasis endemic area in Puerto Rico, before ground reconnaissance.



Figure 2.

Topographic map shown in Figure 1, after ground reconnaissance, and with the portions of streams with host snails enhanced. These are the areas where Calladium is most abundant.



Figure 3.

Endemic schistosomiasis area in Puerto Rico. One stream has been cleared, the other can be traced mostly by the luxuriant growth of Calladium sp.

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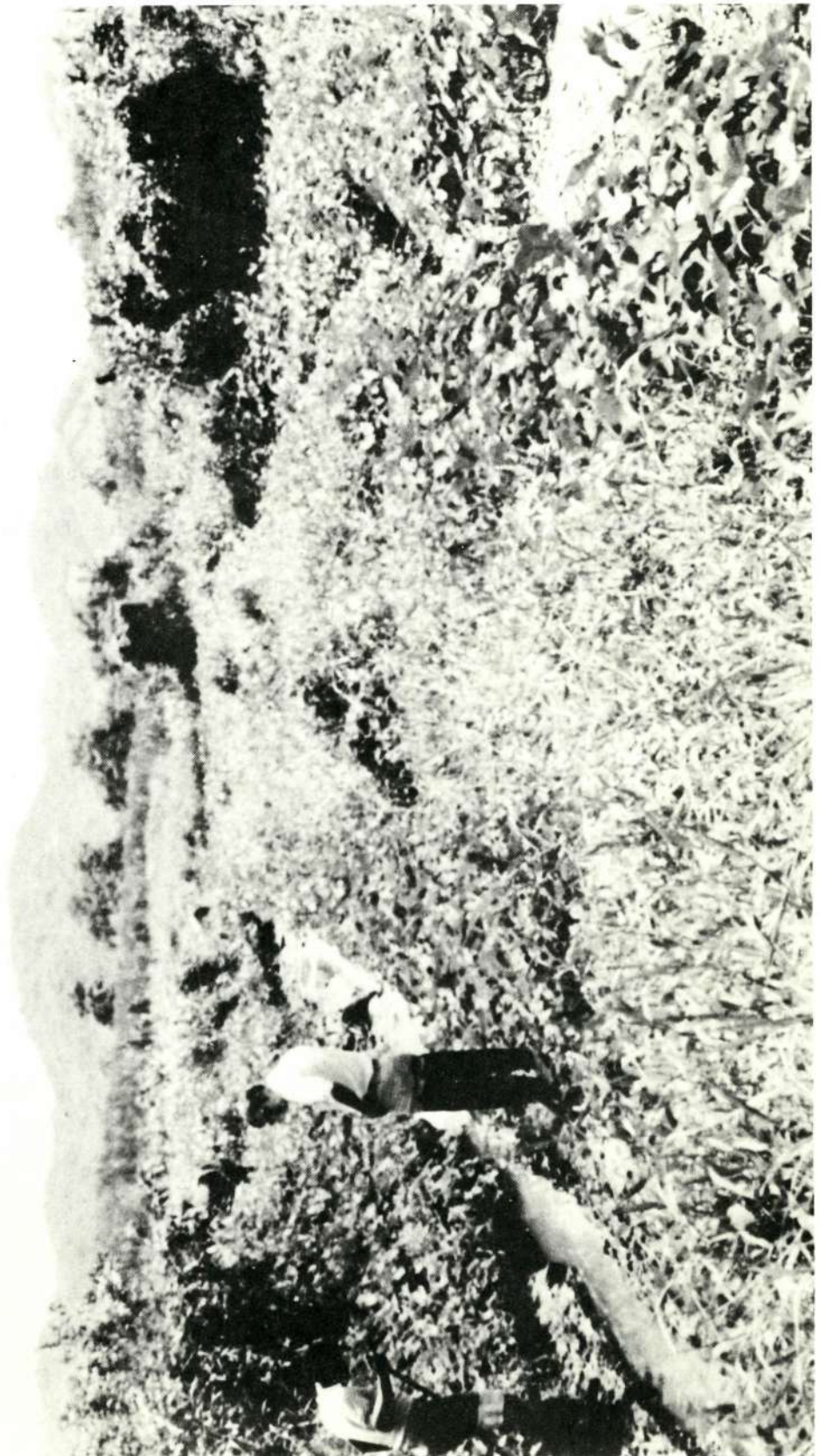


Figure 4.

Volcanic slope on the Pacific littoral of Guatemala -
the endemic zone of onchocerciasis. Note the difficult
terrain, coffee plantations on the slopes.

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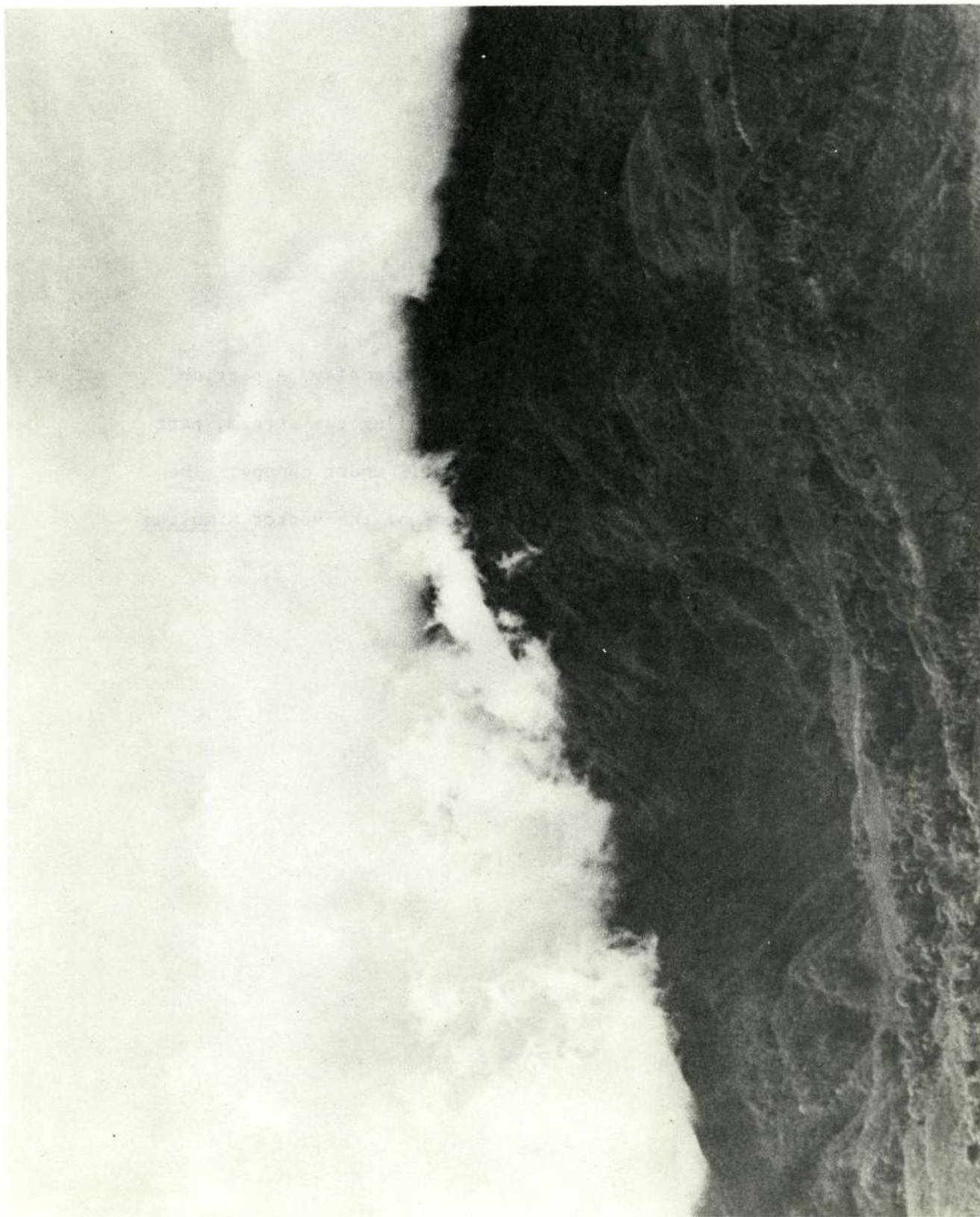


Figure 5.

Endemic zone of onchocerciasis in Guatemala. A portion of the forest has been cleared revealing the stream, part of which on the upper slopes is still under canopy. The stream is the habitat of the larvae of the vector Simulium species.

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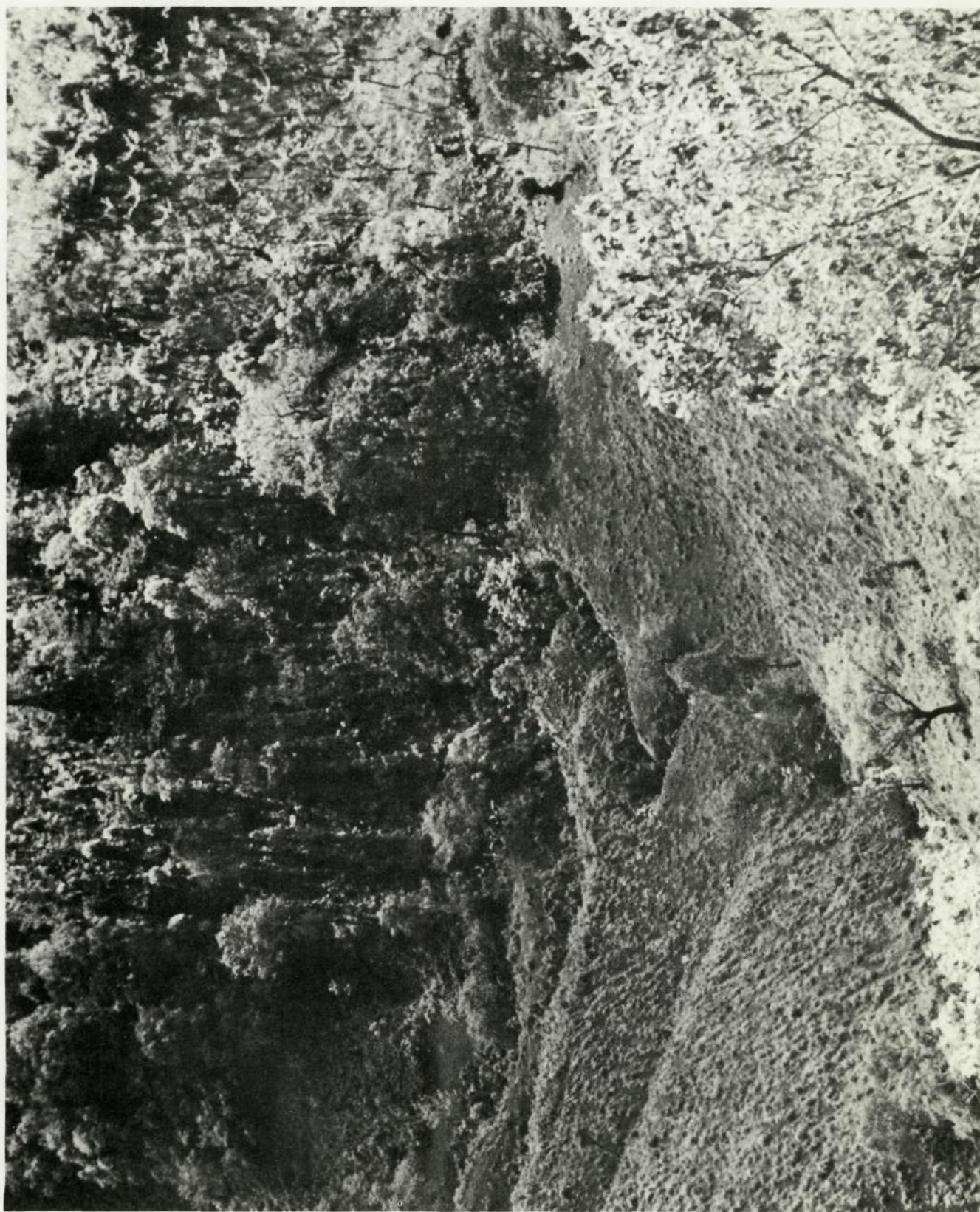


Figure 6.

Stream habitat of larval blackflies in the endemic zone of onchocerciasis in Guatemala. Most of the vectors use these very narrow streams as breeding sites, generally under heavy forest canopy.

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